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ART. XXXIII.—*The Notocene Geology of the Middle Waipara and Weka Pass District, North Canterbury, New Zealand.*

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[Read before the Wellington Philosophical Society, 22nd October, 1919; received by Editor, 31st December, 1919; issued separately, 16th July, 1920.]

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INTRODUCTION.

THE younger rocks of New Zealand, embracing all marine strata from Albian to Pliocene, consist in nearly all localities of accordant rock-series, and form, broadly speaking, a structural and physiographical unit. The rocks composing them—viz., conglomerates, sandstones, greensands, mudstones, and limestones—are much less indurated than the unconformably underlying greywackes, argillites, phyllites, schists, or granites, and physiographically form a weak cover to a resistant undermass. Unlike the latter,

they are rarely strongly folded, except in the neighbourhood of strong faults, and in general exhibit only a tilting or warping which they share equally with the undermass as a consequence of block-faulting. Owing to their softer nature they rarely occur far up the slopes of the tilted blocks, but are confined to the lower levels near the fault-angles.

The ages of the lower and upper members of these younger rocks vary greatly in different districts in New Zealand, and there is no locality where a complete series is found in superposition. Consequently it has seemed desirable to give them in their totality a descriptive name—viz., the Notocene—and to define it by diastrophic considerations as embracing all the beds deposited between the post-Hokonui and Kaikoura deformations (Thomson, 1917, p. 408).

The Notocene may be divided into the following divisions:—

TABLE I.—DIVISIONS OF THE NOTOCENE.

Groups.			Stages.	Probable Correlation.
Wanganui	..	..	{ Castlecliffian	Upper Pliocene.
			{ Waitotaran	Lower Pliocene.
Oamaruan	..	..	{ Awamoan	Upper Miocene.
			{ Hutchinsonian	
			{ Ototaran	Lower Miocene.
			{ Waiarekan	Oligocene.
			{ Ngaparan	
Kaitangata	..	..	{ Paparoan	
			{	Danian to Eocene.
Piripauan	..	..	..	Senonian.
..	..	..	..	Turonian-Cenomanian.
Clarentian	..	..	..	Albian.

In 1919 I gave a description of the Notocene sequence in the Clarence Valley, Marlborough, which ranges from Clarentian to Awamoan, and possibly to Waitotaran. The North Canterbury Notocene sequence described in the present paper includes marine rocks ranging from the Piripauan to the Waitotaran, with an overlying terrestrial series of possibly Castlecliffian age. These rocks form a tilted strip running from the neighbourhood of Mount Grey north-east across the Waipara River in its middle reaches, and across its tributary the Weka Creek, occupying the whole of the Weka Pass, and thence continuing nearly east for eight miles or more a little to the south of the Waikare River. This strip is bounded on the north-western side by the pre-Notocene rocks of Mount Grey, the Doctor's Range, and the hills south of the Waikare River, except for a short distance near the township of Waikare, where its lower members abut against the recent alluvium of the Waikare River. On the south-east the upper members dip under the continuous gravel-plain of the Kowhai and Waipara Rivers and their tributaries. The area covered by these Notocene rocks may conveniently be known as the Middle Waipara and Weka Pass district, in distinction to the Upper Waipara district, near Heathstock, and the

Lower Waipara district,* between the township of Waipara and the sea, in both of which localities similar developments of Notocene rocks occur. These locality distinctions have already been made by McKay. The Middle Waipara and Weka Pass areas form a continuous district, but as they have separate access by road, and as there is no road traversing and connecting them, they are often treated of as separate districts. It should be noted that in the earlier literature the term "Waipara" was generally used for the Middle Waipara area alone, but that the term is now generally used colloquially by geologists for the whole of the Middle Waipara and Weka Pass district. In old reports the part of the Middle Waipara district between Bobby's Creek and the Waipara River is sometimes termed "the Ram Paddock," a self-explanatory name referring to its use when part of the Glenmark Station.

In the history of Notocene geology the district of the Middle Waipara and Weka Pass has attracted more attention than any other in New Zealand, and the Notocene sequence there displayed was made by Hector, Hutton, and von Haast the basis of their various schemes of classification of the Notocene; but, although the district is perhaps the most often quoted in our geological literature, no comprehensive account of the whole Notocene stratigraphy has been attempted since that of Park in 1888. Since that date many new observations have been made, a great deal more is known of the fossils from the various beds, and, moreover, new viewpoints have been found, so that a new account has become desirable. In attempting it I can lay no claim to exhaustive treatment, as there are many outcrops which I have not traversed, and every fresh visit to the district brings to light new fossil forms from the old localities, and new fossil-localities. There is abundant scope for further exploration, and the detailed survey of parts of the area may be suggested as useful theses for students. Still, the major outlines both of stratigraphy and of palaeontology can now be stated, and their bearing on the systems of classification of the younger rocks of New Zealand needs pointing out at the present time.

The map accompanying this paper (fig. 1) does not claim to be more than a sketch-map, and is in large part based on previous maps.

Although the attached bibliography includes a very large number of papers, a minority contain descriptive matter relating directly to the stratigraphy or palaeontology of the district, and the majority deal mainly with the correlation of the various beds and their place in general classifications of the younger rocks of New Zealand. These latter papers are concerned mainly with the validity or otherwise of the Cretaceo-Tertiary formation of Hector, a formation based, first, on the conformity of the Amuri limestone, Weka Pass stone, and "grey marls" within the district, and, secondly, on certain correlations believed to exist between the various rocks of the sequence and those of the Oamaru and West Coast areas. It will make for clearness if these matters are treated in separate sections of this paper.

PART I.—DESCRIPTIVE GEOLOGY.

GEOLOGICAL EXPLORATION OF THE DISTRICT.

The subjoined table, showing the dates of the principal visits of geologists who have written on the district, will give some idea of the interest it has created amongst New Zealand geologists. The list does not include many other visits by those who have not published their observations.

* Also known as "Double Corner."

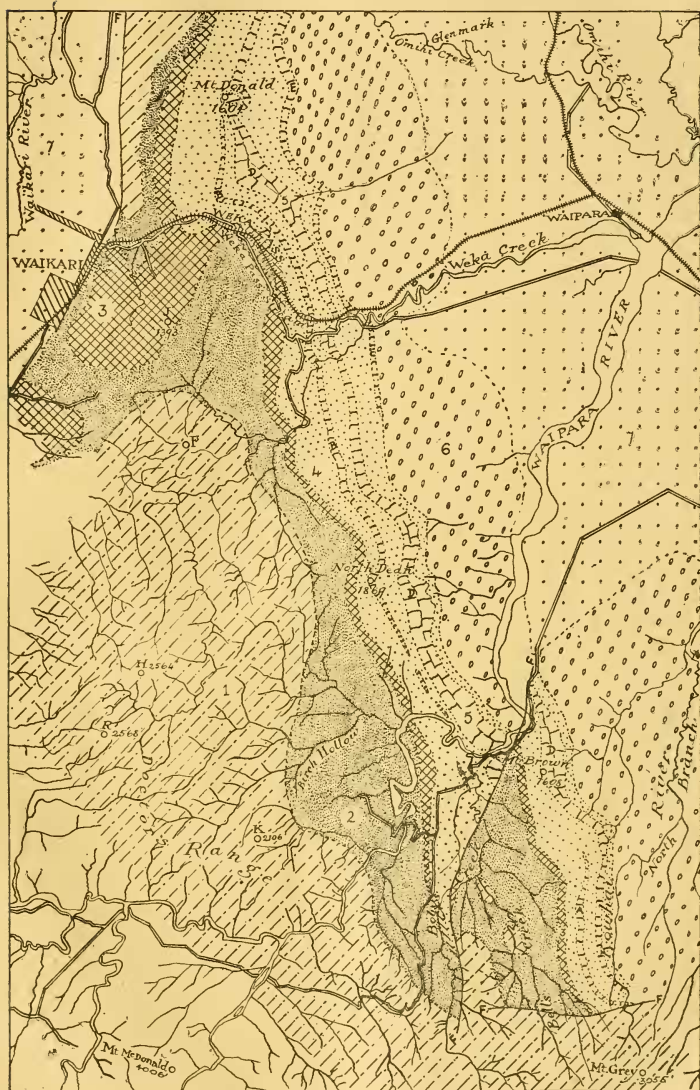


FIG. 1.—Geological map of the Middle Waipara and Weka Pass district. Scale, $\frac{1}{2}$ in. to one mile. The sides of the map are $N. 71^{\circ} E.$ 1, Pre-Notocene. 2, Piripauan. 3, Amuri limestone and Weka Pass stone. 4, "Grey marls" and sands interbedded with 5, Mount Brown limestones. 6, Greta and Kowhai beds. 7, Notopleistocene (alluvial plains).

TABLE II.—DATES OF THE PRINCIPAL VISITS OF GEOLOGISTS TO THE DISTRICT.

Date of Visit.	Date of Publication (see Bibliography).
C. Forbes—1849	1855.
T. H. Cockburn Hood—1859	Owen, 1861.
1868	1870; Haast, 1870A.
Sir J. von Haast—1864, 1866, 1867 (three visits) ..	1869.
1869	1870; 1871.
1875	1879.
Sir J. Hector—1867	1869.
1873-74	1877A.
1886	1887A.
A. McKay—1872 (as collector for Canterbury Museum)	
1874	1877 A, B.
1876	1877C.
1886	1887A.
1891	1892.
F. W. Hutton—1873	1877.
?1884	1885B.
1886	1888.
J. Park—1887	1888.
1904	1905.
1912	1912.
P. Marshall, R. Speight, and C. A. Cotton—1910 ..	1911; Cotton, 1912.
J. A. Thomson—1912	1912 A, B.
1913	1913.
1914, 1917, 1919.	
P. G. Morgan—1915	1915; 1916 A, B, C; 1919.
R. Speight and L. J. Wild—1917	1918; 1919.
R. Speight—1918	1919.

The earliest notice of the district is that of C. Forbes (1855), who was assistant surgeon to H.M.S. "Acheron." He describes a journey up the bed of the Kowhai River to the foot of Mount Grey and a descent by the Karetu River, a tributary of the Okuku. The area he traversed thus probably lies just outside that treated in this paper, but he deals with the upper Notocene rocks of the same strip. He mentions the tilted gravels, since assigned by Speight (1919) to the Kowhai series, and a stratum of hard blue clay dipping south-east at an angle of 35° and containing an immense number of marine shells, the genera of which are specified. The blue clay underlies sandstone, and higher up the river similar beds are represented by dense, hard, blue limestone. These sandstones and blue clays belong doubtless to the Greta series (Waitotaran), and are obviously Tertiary, although Forbes expresses no opinion on this point.

In 1859 T. H. Cockburn Hood discovered and collected saurian remains in the bed of the Waipara River and forwarded them to the British Museum. These fossils were described by R. Owen (1861), under the name of *Plesiosaurus australis*, and referred to the Jurassic period. This find stimulated great interest among geologists, although the early visits of von Haast and Hector were fruitless so far as further specimens were concerned. In his first visit, in 1864, von Haast apparently mistook the cup-shaped Polyzoa from the lower Mount Brown beds for saurian vertebrae, and in consequence considered the saurians as survivors into the Tertiary. In 1870 he acknowledged his mistake and credited the discovery of the true position of the "saurian beds" to Hector. The next considerable collection of saurian remains was again made by Cockburn Hood, in 1868, but on their way to England the specimens were unfortunately lost through the wreck of the ship "Matoaka." Von Haast had fortunately made drawings and taken measurements of the more important bones, on which he published a note in 1870.

Cockburn Hood in 1870 gave a description of the locality and the rocks from which he obtained his collection.

Following Cockburn Hood's successful search, Hector in 1868 sent R. L. Holmes to collect for the Colonial Museum, and he obtained a "fine series of specimens," principally from a tributary of Bobby's Creek (*cf.* Hector, 1869, p. xi). Drawings of these, forwarded by Hector to Owen, enabled the latter in 1870 to add two further species to the fauna—viz., *Plesiosaurus crassicosatus* and *P. hoodii*. Hector in 1874 described other species from Holmes's collection, and mentions also a specimen collected at Bobby's Creek by W. T. L. Travers.

In 1872 von Haast employed A. McKay to collect for the Canterbury Museum, and it was his success in this task that later led to his employment in the Colonial Museum and Geological Survey. McKay subsequently collected further saurians for the Colonial Museum in 1874, but in 1877 he reported that all the more accessible specimens had been secured and further collections could only be made at considerable labour and expense. Nevertheless, in 1891 he was successful in recovering a specimen which he had first seen in 1874, but which had been for some years covered up by river-shingle. McKay's experience, as stated in 1892, was that "nearly all the boulders [concretions] that contain bones split in falling from the cliffs, or in being shifted along the river-bed, and it is never worth while to open a boulder so situated that does not show the presence of bones."

In 1876 or 1877 Hector exchanged "250 specimens, fossil Reptilia of New Zealand" with the Trustees of the British Museum, and descriptions of these were included by Lydekker in the *Catalogue of Fossil Reptilia and Amphibia* in 1888 and 1889. Hutton in 1894 described one of the specimens collected by McKay for the Canterbury Museum in 1872. Since 1892 no fresh collections of saurians from the district have been made, but the interest of geologists has been sustained for another reason—namely, the apparent conformity of the beds containing the saurians with others containing a purely Tertiary fauna.

The first general account of the geology was given by Hector in 1869, who noted that the saurian beds were intimately associated with, but probably underlay, blue and grey marly sandstone, sometimes passing into chalk, and were in turn underlain by white and brown sandstones containing coal-seams, and correlated with the Wealden. These three formations were covered unconformably by Miocene white and yellowish calcareous sandstone, in parts composed altogether of cup-shaped Polyzoa, and by reddish limestone, composed of comminuted shells. On these Miocene rocks rests Pliocene blue clay with beds of sand and gravel containing many existing species of marine shells. Hector gave no account of the structure, but stated his belief that the underlying "Triassic" rocks had been denuded into hills and valleys long prior to the Tertiary period. As Hutton pointed out in 1885, Hector did not distinguish between the "grey marl," the Weka Pass stone, and the Amuri limestone, but considered them all as a "blue-grey marly sandstone sometimes passing into chalk." The unconformity here postulated Hector always adhered to, the lower group becoming later his Cretaceo-Tertiary formation, and the middle (Miocene) his Mount Brown beds, or Upper Eocene.

The next account of the district, by von Haast (1871), was based on a detailed survey of the Middle Waipara part of the district, carried out under Hector's direction for the Colonial Geological Survey, and was accompanied by a map. Von Haast gave a detailed account of the beds in the Waipara River and in Bobby's Creek, the most detailed account yet given so far as the beds below the Amuri limestone are concerned; but, like Hector, he

did not distinguish between the latter rock and the Weka Pass stone. The succeeding "grey marls" he considered as strongly unconformable to the underlying groups, and so showed them on his map; but, as Hutton pointed out in 1877, he failed to recognize the strong fault crossing Bobby's Creek, which brings the middle Notocene against the older Notocene. Von Haast's map shows three inliers of the pre-Notocene within the Notocene of the Bobby's Creek watershed, and these he considered as islands in a large pre-Notocene bay, along the shores and round the small islands of which the lower strata were first deposited in shallow water. His map also shows in approximately correct position a small detached outcrop of calcareous sands (Amuri limestone) in the upper part of Bobby's Creek, which has escaped notice by all subsequent observers. In his next account of the district, in 1879, von Haast still adhered to an unconformity between the lower Waipara (Cretaceo-Tertiary) formation and the "grey marls" forming the base of the Oamaru (Upper Eocene) formation.

Hutton in 1877 referred to the district in a general account of the geology of the north-east part of the South Island, and, as in his later writings, dealt summarily with the beds below the Amuri limestone, but emphasized the importance of the contact* between the Amuri limestone and Weka Pass stone, which in his opinion unconformably separated a lower—Waipara (Upper Cretaceous)—formation from an upper—Oamaru (Eocene)—formation. He first introduced the term "Amuri limestone," and considered that this rock was consolidated, jointed, and water-worn before the Weka Pass stone was deposited upon it. As already mentioned, Hutton correctly interpreted the fault in Bobby's Creek, and described another in the upper part of the Weka Pass. Like Hector and von Haast, he considered that the Notocene rocks were deposited in valleys formed in the pre-Notocene ("Lower Cretaceous").

McKay in 1877 (1877A) was successful in finding a saurian in the greensands between the "saurian beds" and the Amuri limestone. As regards the unconformities believed by Hutton and von Haast to exist, he stated that stratigraphically he could find no conclusive evidence of unconformity between the Weka Pass calcareous greensands (base of the Weka Pass stone) and the Amuri limestone; and "if the Weka Pass calcareous greensands belong to the lower Waipara beds, no unconformity can be conceded as far as the uppermost beds of the Mount Brown series." McKay at this date was therefore in substantial agreement with the position taken later by Park in 1888, and by Marshall, Speight, and Cotton in 1911.

In the same year (1877B) McKay gave a detailed account of the "reptilian" beds of Amuri Bluff and the Middle Waipara, and discussed the question of the pre-Notocene physiography. He concluded that it was improbable that the outlines of the present configuration of the area within which the Notocene remnants are found was determined in the pre-Notocene, or that the Notocene was deposited in a large bay, with inlets penetrating the mountain-ranges, but that the evidence pointed to the subsidence of a very wide area until deep-sea deposits were formed, and a subsequent upheaval of mountain-chains, between which, and in the folds of which, the younger rocks have been preserved to the present day. The views thus early put forward by McKay, though receiving little attention at the

* It is customary to term this contact the "junction" between these two rocks; but a junction is that which unites, whereas in the belief of many writers this surface of contact or touching is rather a surface of separation. The term "junction" has probably been adopted because there is practically a passage-zone and not a surface of separation, the zone consisting partly of Amuri limestone with intercalations of greensand and often with borings filled with greensand, and partly of greensand containing small pieces of Amuri limestone.

time, were elaborated by him in later papers on other districts, and, thanks mainly to the physiographical evidence in support brought forward in recent years by Cotton, are now generally accepted by New Zealand geologists.

In 1885 Hutton once more called attention to the contact between the Amuri limestone and the Weka Pass stone throughout North Canterbury, and its importance in respect to the classification and correlation of the Notocene sequence. Within the district he examined the contact at only one point—viz., in a small gorge of the Weka Pass Stream just above the railway-viaduct—and stated that he believed this to be the only section in the neighbourhood where it could be studied. Although the contact is carefully described, the latter statement is quite incorrect, and is of interest as typifying Hutton's general neglect of detailed field-work. Not only may the contact be observed in numerous places within the Weka Pass, as McKay in 1887 pointed out, but it is exposed at short intervals throughout the whole length of the district. Hutton noted the common dip of the two rocks, but again stated his conviction that the water-worn surface of the Amuri limestone, and the presence of pebbles in the lower 6 ft. of the Weka Pass stone, were conclusive proof of unconformity. In addition, an overlap of the Weka Pass stone on to the slate rocks of Mount Alexander at Hurunui was adduced as further proof of unconformity. Hutton also gave lists of fossils from the Weka Pass stone and the "grey marls," showing that these two rocks, along with the Mount Brown beds, belonged to the Oamaru system, and pointed out that the Amuri limestone contained no characteristic fossils, but was always associated with underlying rocks containing remains of marine saurians and Cretaceous Mollusca. Consequently he claimed that the palaeontological break must be between the Amuri limestone and the Weka Pass stone, exactly where the stratigraphical evidence placed it. "If the line between the Waipara and Oamaru systems be taken immediately above the Amuri limestone, hardly any species of Mollusca, perhaps not a single one, will be found on both sides of it; whereas if it be drawn anywhere above the Weka Pass stone there must always be a large number of species found on both sides of it."

The attack thus made by Hutton on the classification adopted by Hector and the officers of the Geological Survey opened a period of very keen controversy, mainly between McKay and Hutton. McKay (1887A) reaffirmed the conformity of the Amuri limestone and Weka Pass stone on the grounds of the strict parallelism of the two rocks, and attempted to explain away the appearances of unconformity. The so-called shattering of the Amuri limestone he attributed to the effects of jointing combined with a downward working of the greensand into the joints, and he published analyses of the Amuri limestone and the supposed pebbles of the same rock in the greensand to prove that the latter were concretionary phosphatic nodules. The Colonial Analyst called the insoluble residue from the Amuri limestone (42.74 per cent.) "almost pure sand (fine-grained)," and McKay suggested that, as the limestone was less than 50 ft. thick in the Weka Pass, "should the percentage of sand be much increased, the equivalent beds three or four miles distant might very well be mistaken for other than they are, or be absent," and hence overlap of the Weka Pass stone was no necessary proof of unconformity. He further cited a number of species of fossils from the Amuri limestone or lower beds which were also found in higher beds, the majority of his list, however, being from localities outside the district. Hector (1887A), in commenting on McKay's paper, accepted the "definite chemical proof that the supposed fragmental layer at the base of the Weka Pass stone is truly concretionary," and published a map and section of the Weka Pass showing an unconformity between the "grey marls" and the overlying Mount Brown beds.

In 1887 Hutton (1888) examined the sections made in the construction of the railway through Weka Pass, and distinguished five series of beds—viz., (1) the Amuri limestone and underlying greensandstones, (2) the Weka Pass stone and the overlying “grey marls” and sandstones, (3) the Mount Brown beds, (4) the Greta beds, (5) horizontal silts and gravels. Besides the unconformity between the Amuri limestone and Weka Pass stone, he admitted another between the Mount Brown beds and the “grey marls.” Lists of fossils of the Mount Brown and the Greta beds were given, the latter being placed in the Pareora system.

Park (1888) records a visit of nine days to the district, and gives an excellent general summary of the geology, accompanied by a map and section. His conclusion as to the presence of unconformities is stated as follows: “As a result of the examination of many of the magnificent sections between the Weka Pass and Waipara, I am strongly of the opinion that a complete sequence of beds exists from the base of the Cretaceous-Tertiary to the close of the Pareora formation, although the varying character of the deposits and their fossil remains show that the sea-bottom on which they were deposited was subject to frequent oscillations.” He accepted the concretionary nature of the pebbles at the base of the Weka Pass stone, but apparently admitted that the surface of the Amuri limestone was water-worn, due to “a sudden arrestment of the downward movement and a return to shallow-water conditions.” The “grey marls” were considered to pass insensibly into the Mount Brown beds: “indeed, it would be difficult to accurately fix or define their boundaries.”

Hector (1888) was obviously embarrassed by this conclusion of an officer of his survey as to the conformity between the “grey marls” and the Mount Brown beds, but contented himself with recording anew his belief in a marked discordance, with great denudation of the “grey marls.”

McKay (1892) re-examined sections in the Weka Creek, and more particularly in the Middle Waipara, paying particular attention to the “saurian beds.” Concerning the contact between the Amuri limestone and the Weka Pass stone, he noted that in the Waipara limestone gorge the green-sand conglomerate and parting-beds of greensand with phosphatic nodules were absent, and that there was no sign of unconformity. He also recorded a stratigraphical unconformity between the “grey marls” and the Mount Brown beds near the mouth of Boby’s Creek, evidently the same as that later recorded by Thomson in 1912 (1912B).

For a period of about twelve years no further examination of the district appears to have been made, and Hector and McKay on the one hand, and Hutton on the other, to the end adhered to the positions they had taken up. In 1905 Park abandoned the Cretaceous-Tertiary classification and accepted a modification of that of Hutton, in reality reverting practically to the position always taken by von Haast. He supposed that the Tertiary (Oamaruan) fossils reported from the Weka Pass stone were in reality obtained from tumbled masses of the Mount Brown limestones, and that the Weka Pass stone itself was unfossiliferous; consequently he included it in the Waipara (Upper Cretaceous) series. The “grey marls,” he included with the Mount Brown beds in the Oamaru (Miocene) series, which rested unconformably on the Waipara system, “the Weka Pass stone and the Amuri limestone being thrown into folds in which the Tertiaries take no part whatever.” The Tertiary beds were described in detail, and fresh lists of fossils were given, including a new fossil-locality for the Mount Brown beds near Mount Donald. Somewhat anomalously, Park rejected Hutton’s name of “Greta beds” for the uppermost marine series, and accepted that of “Motunau beds” instead, although Greta is much nearer to the district than Motunau. These beds had latterly been accepted as

belonging to the Pareora system (Upper Miocene), but Park suppressed that system throughout New Zealand, and correlated the Motunau beds with the Te Aute or Waitotara series, of older Pliocene age, thus returning to the original correlation of Hector (1869) and von Haast (1871). He described an unconformable contact between the Motunau beds and the underlying Mount Brown beds.

It is of interest to note that Park also accepted the earlier views of Hector, Hutton, and von Haast as to the pre-Notocene physiography. He considered that the main mountain features of New Zealand were already determined in the Eocene, and that the present intermont basins were old-Tertiary fiords and inland basins which before the Miocene submergence were merely deep valleys of erosion.

The modern revival of interest in the district commenced with the paper on the younger rock-series of New Zealand by Marshall, Speight, and Cotton, in 1911. They restricted themselves to a critical examination of those localities where unconformities had been reported by earlier observers, and recorded their conviction that there was no unconformity in the Waipara and Weka Pass district. A map and block-diagrams of the Weka Pass were given to explain the erroneous view of Park that the Weka Pass stone and Amuri limestone were thrown into folds in which the Tertiaries take no part. The north-western part of the Notocene strip, from which the upper beds had been denuded, was thrown into folds whose pitch did not carry them beneath the south-eastern part, where the Upper Tertiaries are preserved. The peculiar characters of the contact between the Amuri limestone and Weka Pass stone are attributed to a change of conditions of deposition. "The change from pure (Amuri) to glauconitic (Weka Pass) limestone does not take place throughout the mass of the rock, but inter-laminations of glauconitic matter arise and separate pieces of limestone. As the conditions that control the depositions become more changed the inter-laminations of glauconitic matter become larger, and the pure limestone is reduced to nodules which appear like rolled pebbles." The contact relied on by Hutton for an unconformity between the "grey marls" and Mount Brown beds was considered a fault-contact within the Mount Brown beds. The section on which Park relied for an unconformity between the Mount Brown and Greta beds was described as showing complete conformity. The authors did not express clearly their views as to the pre-Notocene physiography, but apparently agreed with the view, accepted by all others than McKay, of a diversified surface admitting of considerable overlap within a very short distance.

A period of controversy between Park and Marshall then ensued as to the conformable or unconformable nature of the Lower Tertiaries and Upper Cretaceous of New Zealand. Park's first reply (1911) did not deal with the internal geology of the Weka Pass and Waipara district, but disputed the correlations made with rocks of the Oamaru district, and reaffirmed unconformity between Cretaceous and Tertiary on palaeontological grounds. Thomson (1912 A and B) recorded a fresh discovery of Oamaruan fossils in the Weka Pass stone, and noted an unconformity within the sandy beds between the Weka Pass stone and the lower calcareous horizon of the Mount Brown beds, in a cliff of the Waipara River gorge, just above the junction with Bobby's Creek. "It appears, however, to be a purely local accident of bedding. With this exception, there is apparent conformity in section throughout the Waipara district." Marshall in 1912 quoted the fossils from the Weka Pass stone, which Park had admitted as conformable to the Amuri limestone, as proving Park's adhesion to the conformity of the Upper Cretaceous and Lower Tertiary. Park (1912, 1913) inspected the new fossil-locality, accepted the Weka Pass stone as Oamaruan, but

reaffirmed his belief in a necessary unconformity on palaeontological grounds, which he therefore placed, with Hutton, between the Amuri limestone and Weka Pass stone, and cited unconformities on the same horizon in other districts, and the controversy shifted to these.

Thomson (1913) described new fossil-localities in the Weka Pass stone at Onepunga and in the Mount Brown beds near the junction of the Weka Creek and the Weka Pass Stream. He expressed the opinion that "although a classic locality for the determination of the relationships of the Cretaceous and Tertiary beds, the Middle Waipara and Weka Pass district is not well suited, owing to its poverty in molluscs, to become the standard of reference for the Tertiaries of New Zealand."

Morgan (1915) described the section exposed in the gorge of the Weka Pass Stream near the railway-viaduct and in its upper valley, agreeing with the explanation of the structure put forward by Marshall, Speight, and Cotton, and devoted special attention to the contact of the Amuri limestone and the Weka Pass stone. The conclusion, stated to be tentative, was that the facts appeared to be clear proof of at least local unconformity. The same writer in 1916 (1916B) described the contact in the country between the Weka Creek and the Waipara River, recording the occurrence of small, extremely black, phosphatic pebbles in the glauconitic sandstone to a height of 4 ft. above the Amuri limestone surface, also one or two quartz pebbles and a pebble of flint, and also worm-borings now filled with glauconitic matter in the Amuri limestone. He noted that in the gorge of the Waipara River there was no sign of visible unconformity, but considered that it was still possible to accept the Amuri limestone and Weka Pass stone contact as representing a stratigraphical break. He cited a contact visible in a small gorge of Weka Creek as very satisfactory proof of the unconformity maintained by Hector and McKay as present between the "grey marls" and Mount Brown beds. Sections were also given showing the Quaternary age of some of the faults of the district.

Speight in 1915 discussed the geology of the intermont basins of Canterbury with a view to arriving at a proper conclusion as to the pre-Notocene physiography, and whether or not the present Notocene beds were originally laid in discontinuous deposits or are the remains of a widely distributed cover which once masked the greater part of the surface of the country. He concluded in favour of the latter view, with the restriction that they did not form a complete veneer over the whole surface, but that elevations that survived the prior period of erosion projected like islands through the Tertiary sea, and may in some cases have been sufficiently high to form sanctuaries for the Antarctic element in the New Zealand flora.

Marshall in 1916 described the minute structure of the younger limestones of New Zealand, including specimens of the Amuri limestone and the Weka Pass stone from the Weka Pass. He found the Amuri limestone to consist mainly of very finely grained calcite, with fairly numerous, isolated chambers of *Globigerina*. Near the contact it contained a considerable number of grains of quartz sand and some glauconite, as well as some brown mica, together with different and larger species of Foraminifera, including *Cristellaria* and *Rotalia*. These characters, emphasized to a greater extent, were the features that distinguished the overlying Weka Pass stone from normal Amuri limestone. The microscopic structure and relations of these limestones served to indicate a strong resemblance between these stones near their contact, and such differences as there were would be a natural result of the shallowing of the water and of an increase in the velocity of the ocean currents. The depth of deposit of the Amuri limestone, a pure *Globigerina* ooze, was estimated at from 600 to 2,500 fathoms. Its age was considered to be Miocene.

Thomson (1916) discussed the age and mode of origin of the Amuri limestone throughout North Canterbury and Marlborough, quoting fossils from it at Amuri Bluff and the Trellissick Basin (discovered by Speight and Thomson) which proved the fossil-horizons to be Tertiary. As these occurred near the top of the limestone, which was always underlain by Cretaceous rocks, he concluded that it was in itself a Cretaceo-Tertiary rock—Cretaceous at the base and Tertiary at the top. He pointed out that the appearances of unconformity between the Amuri limestone and Weka Pass stone were not present where the base of the latter rock was not glauconitic, and concluded, therefore, that it was a purely local phenomenon, and not indicative of a non-sequence of any extent. He suggested that the Amuri limestone was in large part a chemical deposit, its silica content and its poverty in fossils becoming then easily explicable.

In 1917 Woods described the Cretaceous fossils of North Canterbury and east Marlborough in the collections of the Geological Survey. He found that rocks of two ages were represented, those of east Marlborough, north of Amuri Bluff, developed especially in the Clarence Valley (*cf.* Thomson, 1919) and the Awatere Valley, being of Lower Utatū (approximately Albian) age, and those of Amuri Bluff, Waipara and Weka Pass, and the Malvern Hills being Upper Senonian. In the Middle Waipara and Weka Pass district all the fossils came from the *Ostrea* bed and the "saurian beds," and in most cases were poorly preserved.

Thomson (1917) proposed the local terms "Clarentian" and "Piripauan" for the two groups of Cretaceous rocks correlated by Woods as "Albian" and "Upper Senonian" respectively, basing them on the rock-sequences below the Amuri limestone of the Clarence Valley and Amuri Bluff. He criticized the grouping of all the younger rocks of New Zealand by Marshall as a strictly conformable series deposited during a single cycle of depression and elevation, the period of maximum depression being everywhere contemporaneous, on the grounds that the Amuri and Oamaru limestones were of different ages and that unconformities are present in some districts. He rejected also Marshall's use of the name "Oamaru" for a system to include all the younger rocks, both on grounds of priority and because only a small part of them were developed at Oamaru, but admitted the necessity of an inclusive name for them in view of their diastrophic unity as more or less accordant rocks, deposited in a period of relative diastrophic inactivity between two periods of major diastrophic activity, and proposed the name "Notocene." The references to the Waipara and Weka Pass district were mostly to questions of correlation, but a summary of the succession from the coal-beds at the base to the Weka Pass stone was given with a view to showing the thinness of the beds between the highest known Piripauan and the base of the Amuri limestone. The tilted gravels unconformably overlying the marine succession in the Kowhai River were also briefly discussed.

Park (1917) suggested that not only was the tuff-bed recorded by Thomson and Speight in the Amuri limestone of the Trellissick Basin Oamaruan, but the whole of the Amuri limestone throughout New Zealand should be placed in the Tertiary, and an unconformity looked for below it, probably between the "saurian beds" and the overlying greensands, in which latter Haast had recorded a Recent brachiopod in the Middle Waipara.

In 1917, also, Trechmann described Cretaceous Gasteropoda from New Zealand, mostly from the Selwyn Rapids, but one species from the *Ostrea* bed of the Waipara Gorge was included.

Speight and Wild (1918) gave a careful and very detailed description of the contact between the Amuri limestone and the Weka Pass stone, not

only in the Middle Waipara and the Weka Pass, but also in numerous other localities in the region between Mount Grey and the Puhipuhi Valley. They distinguished between the two rocks a transitional layer, generally termed the "nodular" band or layer, which was uniformly about 1 ft. thick over an area of 100 miles by 15 miles, and was composed of phosphatic concretions and nodular masses of phosphatized Amuri limestone in a matrix of greensand or marl, with very occasionally some well-rounded pebbles of quartz and greywacke. The remarkable uniformity in the thickness of this layer over such an area was inconsistent with its being a shore-line deposit, and the character of the phosphatic pebbles pointed to their formation in a depth of over 100 fathoms. The upper surface of the Amuri limestone was not, they considered, an erosion surface, but one honeycombed by the borings and burrowings of marine organisms operating on the sea-floor at a considerable depth, with possibly some solution of calcareous matter by the solvent action of sea-water during a period of halt in the deposition. The borings were filled with the materials of the overlying bed and not by beach deposits. The rigorous parallelism of the Amuri limestone, the nodular layer, and the Weka Pass stone over such an area were inconsistent with a theory of unconformity by emergence and erosion. They therefore concluded that there was no unconformity, but that some alteration in depth or in the conditions of deposition no doubt occurred, which was of no greater amount than that which takes place when a bed of different lithological character is laid down in a perfectly conformable sequence. In describing the Middle Waipara occurrences the authors indicated the existence of a well-defined fault-scarp along the east face of Mount Grey, limiting the extension of the Notocene beds in this direction. In 1919 the same authors discussed the nodular layer as a commercial source of phosphate.

Thomson (1919) discussed once more the age and origin of the Amuri limestone in Marlborough and Canterbury, arguing that it was in large part a chemical deposit on the outer slopes of the continental shelf. He accepted the view of Speight and Wild as to the conformity of the Amuri limestone and Weka Pass stone, and considered the contact as a plane of non-deposition, which he suggested might be due to a change of conditions putting a stop to chemical deposition, while the formation of purely organic ooze might be so slow as to allow time for the boring of the last-formed bed and the phosphatization of its upper surface before the deposition of the foreset greensand began. Dealing with Park's suggestion for an unconformity between the "saurian beds" and the Waipara greensands, he reaffirmed the Senonian age of the latter beds, rejecting Haast's determination of the brachiopod as Recent, and considered that if any disconformity existed it should be looked for above the Waipara greensands in the dark carbonaceous mudstone down into which the Amuri limestone passes.

Speight in 1919 gave a description of the tilted gravels of the Kowhai, Grey, and lower Waipara Rivers, and proposed for them the name of Kowhai* series. He concluded that the age was most probably Pleistocene.

Morgan (1919) gave a general description of the limestones of the area, summarizing previous knowledge. He reaffirmed his belief that there is a true disconformity between the Amuri limestone and Weka Pass stone, and that it denotes a considerable time-interval.

* Speight spells the name "Kowai." The Lands Department maps give "Kowhai" for the river draining from Mount Grey and Mount Brown, and "Kowai" for the tributary of the Waimakariri River, and the distinction appears a convenient one. If Maori orthography is to be strictly followed, "Kowhai" should be used in both cases.

GENERAL ACCOUNT OF THE GEOLOGY AND PHYSIOGRAPHY.

As in all districts where any development of the Notocene is present, there are three main classes of rocks, viz. :—

- (1.) Pre-Notocene: in this case greywackes and argillites, strongly folded, indurated, and jointed, and truncated by an erosion surface, on which rests unconformably—
- (2.) Notocene (as in Table III below): the rocks are only moderately indurated, and then well jointed, but are not in all cases cemented; they are for the most part strongly tilted, only locally folded, and are often faulted.
- (3.) Notopleistocene: horizontal, for the most part unconsolidated, terrace and river silts and gravels.

The main subdivisions of the Notocene are shown in Table III.

TABLE III.—GENERAL CLASSIFICATION OF THE NOTOCENE ROCKS OF THE DISTRICT.

Age.	Local Name.	Nature of Rocks.
Wanganuian	Kowhai beds	Terrestrial gravels.
	Greta (or Motunau) beds	Marine gravels, silts, and blue calcareous mudstones with gravelly shell-beds.
Oamaruian ..	Mount Brown beds ..	Rubby impure limestones and calcareous sandstones, interbedded with sands.
	"Grey marls"	Grey calcareous and sandy mudstones, sandstones, and sands.
	Weka Pass stone and Weka Pass greensand	Limestone and calcareous sandstone, passing down into a calcareous greensand with phosphatic nodules.
Kaitangatau	Amuri limestone ..	Chalky limestone, passing down into marls and glauconitic mudstones.
Piripauan ..	Waipara greensands ..	Glauconitic sands with hard, thin beds of greensandstone.
	"Saurian beds" ..	Purple glauconitic mudstones passing down into sands, both with yellow efflorescence.
	<i>Ostrea</i> bed	Sandstone cemented by poecilitic crystals of calcite, resting on a shell-bed mainly composed of oyster-shells.
	Coal-measures	Carbonaceous shales, limonitic sandstones, and sands with thin seams of coal.

STRUCTURE.

The general geological structure of that part of North Canterbury within which the district lies consists of elevated folded or tilted blocks with a general north-east and south-west trend, separating lowland areas which in the interior are intermont depressions. Broadly speaking, the elevated blocks may be regarded as anticlines and the depressions as synclines, though they are in many places bounded by faults on one or other side. The folding and faulting has been of geologically young age, after the close of the Notocene deposition, and is doubtless due to the same (Kaikoura) orogenic movements as caused the elevation of the Kaikoura Mountains. Since these movements erosion has largely stripped the Notocene cover from the higher parts of the anticlines or tilted blocks, so that it is now found only on the lower slopes, and the resulting deposition has partially filled the synclines or fault-angles with horizontal Notopleistocene alluvium.

One such lowland area is the Amberley-Waipara Plain, which is a northern continuation of the Canterbury Plain, from which it is nearly cut off by the Moeraki Downs, consisting of tilted late Notocene gravels. This plain, 135 ft. above sea-level at the township of Amberley, and 231 ft. at the township of Waipara, slopes down south-east of the former place to low cliffs near the sea, but farther to the north-east it leaves the coast and enters an elliptical basin, crossing the Waipara River and extending some distance up the tributary Omihi Valley, being separated from the sea by the anticlinal elevation of Mount Cass. The lowland area extends farther to the north-east than the actual alluvial plain, and passes by way of the Greta Valley into the lower Hurunui Valley.

A second lowland area, farther inland and roughly parallel to the first, is the Hurunui-Waiiau intermont basin, 567 ft. above sea level at Culverden, which is drained by the Hurunui and Waiiau Rivers. The south-western extension of this basin reaches the upper Waipara River near Heathstock, while a small lateral extension on the south-east side reaches the headwaters of the Waikare River near the township of Waikare, 733 ft. above sea-level.

The elevated belt separating these two lowland areas is divided by transverse depressions into three main blocks—viz., Mount Alexander (2,448 ft.) to the north-east, the Doctor's Range (2,568 ft.) in the middle, and Mount Grey (3,055 ft.) to the south-west. The north-easterly part is again divided obliquely by a nearly east-west fault, which runs from the neighbourhood of Waikare along the south side of the Waikare River, and separates a subsidiary low block, Moore's Hills, on the south from the higher Mount Alexander block to the north. The lowland area between these two blocks is occupied by the Waikare Valley, and is continuous at its head with the lateral extension of the Hurunui-Waiiau intermont depression, forming the northerly of the two transverse depressions in the elevated belt. The southerly transverse depression is the fault-angle of a nearly north-south fault on the eastern side of Mount Grey, which lies on the upthrown side of this fault.

The Middle Waipara and Weka Pass district here described forms the lower south-easterly parts of this discontinuous elevated belt between the two main lowlands. The Notocene strip of which it is composed is bounded on its inland side by a fault near Mount Grey, rests unconformably on the pre-Notocene of the Doctor's Range, is thrown into a series of folds between the Weka Creek and Waikare, and at this point has not been completely stripped from the anticline of old rocks, and is again bounded by a fault

south of the Waikare River except for a few miles where it has again been stripped from the pre-Notocene on the summit of the Moore's Hills block. On its seaward side the Notocene strip everywhere dips under the Noto-pleistocene gravels of the Amberley-Waipara Plain. The Notocene beds are, with the exception of the Kowhai gravels, an accordant series, and behave as a structural unit in regard to folding and faulting. The general type of structure is shown diagrammatically in fig. 2.

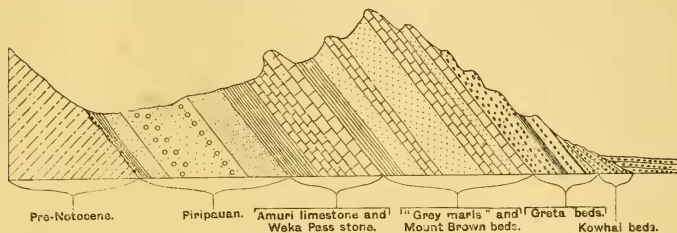


FIG. 2.—A diagrammatic section from north-west to south-east across the district.

The disposition of the Notocene rocks as a simply tilted series with dips to the south-east is modified at various places both by faults and folds. The more important of these are the Mount Grey fault, bounding the Notocene to the south-west; the Bobby's Creek fault, cutting the Notocene strip obliquely and separating the Mount Brown area from the remainder of the strip; and a series of folds transverse to the strip on the north-western side of the Weka Pass.

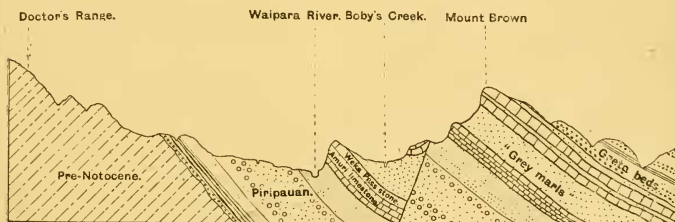


FIG. 3.—Section across the Bobby's Creek fault.

The displacement along the Mount Grey fault is very great—probably over 2,000 ft.—but cannot be accurately estimated, as the Notocene rocks do not occur along the upthrown side. There must have been considerable drag accompanying the formation of this fault, for the limestones of the Notocene, which half a mile north-east of the fault-line strike north-east with a moderate dip to the south-east, become practically vertical near the fault-line and curve round to strike north-north-west.

The Bobby's Creek fault runs west from the Waipara River north-east of Mount Brown, across the lower part and into the upper part of Bobby's Creek, ending against the Mount Grey fault. The downthrow is on the north and east side, and amounts to about 1,300 ft. near the middle, where the "grey

marls " have been brought opposite the coal-beds. On the south side of the fault some anticlinal folding is seen ; the coal-measures occupy a middle position along the fault-line, and thence to the west a complete sequence up to the Amuri limestone may be traced, while to the east a similar sequence up to the Waipara greensands may be seen in Bobby's Creek. On the north side of the fault, gentle anticlinal folding is shown by the " grey marls " in Bobby's Creek below the road-bridge, and synclinal folding in the Main Mount Brown limestone both on the north bank of the Waipara River (see Plate XXI, fig. 1) and alongside the road in the angle between the fault, the Waipara River, and Bobby's Creek.

Near Waikare, where there is a low transverse depression in the main elevated ridge separating the two lowland areas, the Notocene rocks have not been stripped from the pre-Notocene on the axis of the elevation, but continue across the saddle, and extend into the Hawarden area. There is thus anticlinal folding parallel to the elongation of the Notocene strip, but the structure is complicated by the presence south of Waikare of a syncline and anticline transverse to the elongation of the strip. As these folds, exhibited only in the lower Notocene beds, do not continue to the south-eastern side of the Weka Pass, where the upper Notocene beds outcrop, it was at one time considered that they were a proof of unconformity ; but the structure was satisfactorily explained by Marshall, Speight, and Cotton (1911), whose diagrams are here reproduced (fig. 4). Without doubt the Mount Brown beds formerly extended north-west across the pass, and shared the same folding, but have since been removed by erosion.

Besides the above more important structural features there are a number of minor faults, with throws from a few inches to several feet, one of which, in the railway-cutting 43 $\frac{3}{4}$ miles from Christchurch, was mistaken by Hutton for an unconformity.

PHYSIOGRAPHY.

The main elements of the relief of the area under consideration and the surrounding areas were doubtless determined by the Kaikoura orogenic movements, which caused the uplifts of the high-standing blocks—viz., Mount Grey, the Doctor's Range, Moore's Hills, and the Mount Alexander Range—and the (relative) downthrow of the intermont areas of the Heathstock, the Waikare Valley, and the Omihi Valley. The drainage-pattern, however, was probably established in its major outlines during the earlier uplifts of which the Kowhai gravels serve as a record. The Waikare flats and the Heathstock lowland are stated by Speight (1915) to be part of the Hurunui-Waiau intermont depression, which is drained by the Waiau, Hurunui, Waikare, and Waipara Streams, each with its separate gorge through the seaward-lying enclosing ranges. The lowest gap in these ranges, the saddle of the Weka Pass, is not used by any stream, a proof that the above rivers occupied their present courses before the uplift of these ranges took place. They are, therefore, antecedent streams, or anteconsequents if the earlier uplifts are admitted as only earlier stages of the main uplift.

Following the main later uplifts fresh consequent streams would come into being, the chief of those which traverse our district being the Kowhai River in its main branches, the Weka Creek, and Omihi Creek. These streams, it will be noticed, are widely spaced.

In the period following the later uplifts an early mature topography developed. The presence of hard bands in the Notocene sequence—viz., the Amuri limestone and Weka Pass stone, the various Mount Brown limestones, and the harder sandstones of the Greta series—led to the development

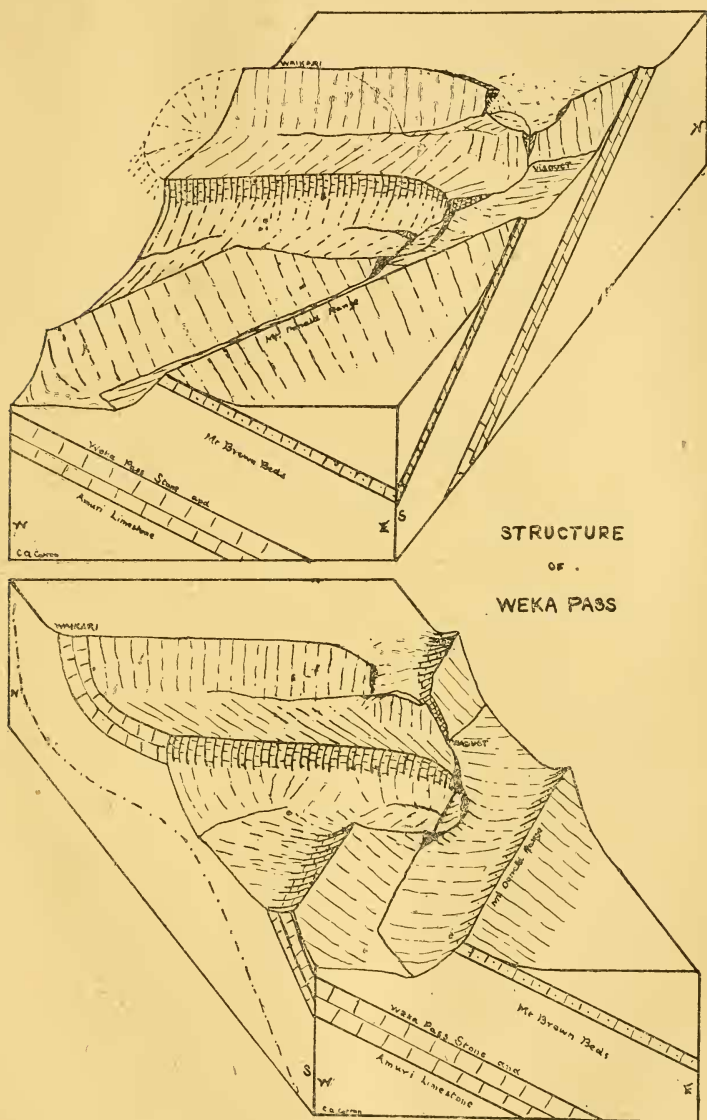


FIG. 4.

of prominent cuestas, of which that of the main Mount Brown limestone (cf. fig. 2) is the highest and most persistent in the middle part of the strip, being breached only by the Waipara River and the Weka Creek. In the south-western part of the district the most prominent cuesta is that of the lower Mount Brown limestone, while east of Mount Donald the Weka Pass stone cuesta rises to equal prominence with that of the main Mount Brown limestone. Although subsequent depressions between the main cuestas were well developed, these were mostly occupied by small tributaries of various consequent or insequent streams, and there are few subsequent streams of any importance. The soft Piripauan beds and "grey marls" were for the most part reduced to low relief, and on them the Waipara River and Bobby's Creek, and to a less extent the Weka Creek, developed broad flood-plains and meandering courses. The texture of dissection of the more porous Notocene was much coarser than that of the higher-standing pre-Notocene, which was characterized by numerous insequents with many rocky ledges.

North-east of Mount Donald the pre-Notocene rocks of Moore's Hills preserve fairly perfectly a fossil peneplain similar to those described by Cotton from Oamaru, Central Otago, the Goulund Downs, &c., including the presence on it of a small outlier of Weka Pass stone. No similar fossil peneplain appears to exist on the Doctor's Range, although the even slope from the height of the range to the saddle north of the Deans seems, when seen in profile, to suggest the presence of such a stripped surface. The reason for its absence near the Doctor's Gorge may possibly be the steepness to which the base of the Notocene has been tilted at this point, rendering it more liable to erosion; but, as the stratigraphy shows the existence of an overlap during the deposition of the Piripauan and Kaitangatan, it appears more probable that the surface on which the Piripauan rests was not peneplained, though peneplanation had become practically perfect on the adjacent land before deposition of the Weka Pass stone.

The mature topography above described has been modified by a later revival of erosion due to regional uplift, which has allowed the Waipara River, the Weka Creek, and their main tributaries to incise themselves more than 100 ft. in the old flood-plains in narrow steep-walled gorges. The revival extends in the main streams right through the Notocene strip and into the adjacent parts of the pre-Notocene rocks, but in the smaller, steep, and mostly dry tributaries draining the back of the cuestas of the Mount Brown and Greta beds has not passed, on the average, more than half their lengths, and the lower gorges through the Kowhai gravels and upper part of the Greta beds end abruptly in sand or gravel cliffs. Incised meanders are a marked feature of the rejuvenated topography, and are well displayed in the Waipara River both above and below the limestone gorge, and in Bobby's Creek, while a beautiful example, superimposed on the pre-Notocene, is shown in the upper of the two inliers of those rocks in Bell's Creek. In the Waipara River the revived valley is graded right through the Notocene strip, but in Bobby's Creek and Weka Creek the grading is not so perfect, and in the former the *Ostrea* beds cause a waterfall of about 20 ft.

The uplift which led to this revival is doubtless the same as caused the raised beaches of 150 ft. and 250 ft., described by Speight (1912), near the mouth of the Waipara River. Its discontinuous nature is shown by a flight of terraces in the Waipara River above the limestone gorge, as figured by Cotton (1919) and shown in Plate XVI. Witness to its recent origin is also borne by numerous cut-off meanders at various heights in Bobby's Creek.

A still more recent revival of erosion is shown by the existence of small channels, a foot or two in breadth and depth, within the rejuvenated portions of the small streams draining from the back of the *cuestas* of the Mount Brown and Mount Donald beds. This revival, in the opinion of Cotton,* may be due to the quicker run-off of storm-water owing to the eating-down of the original plant-covering by stock and rabbits, or to reduction of the plant-covering by slight desiccation of climate.

Caves and underground courses in the limestones are not a prominent feature of the area. Shelters caused by overhanging bluffs of Weka Pass stone are common, and are also developed in places in the Mount Brown limestones. The back slopes of the Weka Pass stone *cuestas* are marked by narrow fissures, generally parallel to the strike, which are mostly choked with clay and debris to a depth of 8–10 ft. They are well displayed on the *cuesta* west of the Waipara River limestone gorge, and on the adjoining "grey marls" there are three large sink-holes occupied by lagoons. Sink-holes are also present in a similar position in the angle between the Weka Creek and the Weka Pass Stream. A persistent series of caves, said to be of considerable depth and extent, occurs at the foot of the Amuri limestone *cuesta* near Onepunga, just in front of the outcrop of the Weka Pass stone. The only underground course I have observed is in the Omih Creek, north-east of Mount Donald, where the stream flows for a short distance underground in the Weka Pass stone. Springs and marshy areas are well displayed in many places and at various horizons where loose sands rest on more impervious rocks—*e.g.*, on the hillside below Trounce's quarry, near Waikare, where sands below the Amuri limestone and glauconitic mudstone rest upon the Waipara greensands.

DETAILED STRATIGRAPHY.

PIRIPAUAN.

The Piripauan rocks of the district include all those *Notocene* rocks below the Amuri limestone and the marls, mudstones, or sandstones down into which it passes. All the fossils obtained from this group have been determined as Upper Senonian, including the *Reptilia* of the "saurian beds," and the presence of *Reptilia* in the overlying Waipara greensands justifies their inclusion also in the Piripauan. The rocks are nearly 800 ft. thick in the Middle Waipara district, but they are not more than 150 ft. a few miles east of the Weka Pass. The thinning-out is due to overlap, since in the eastern end of the district the sequence commences with the uppermost division, the Waipara greensands. Within the Piripauan no unconformity has been detected by any observer. The beds in most cases pass gradually into one another, and the divisions recognized are only for convenience of description.

Coal-measures and Ostrea Beds.

In the western part of the district a bed formed mainly of black oyster-shells is very persistent, but as coal-seams lie sometimes above and sometimes below it it is conveniently included with the coal-measures. The clearest sections are those of the Doctor's Gorge, Waipara River, and in the various tributaries of Bobby's Creek.

* Personal communication.

Doctor's Gorge, Waipara River.—According to von Haast's account (1871), the coal-beds are 150 ft. thick, and consist of rusty-coloured loose sands, with some harder bands of limonitic sandstone, followed by white quartz sands, and enclosing several seams of very inferior lignite and shales, the former from 9 in. to $2\frac{1}{2}$ ft. thick. These in turn are followed by angular, loose, quartzose sands, covered frequently with an efflorescence of sulphur, and not showing any stratification. They strike north and south, with an easterly dip of 33° , and rest on pre-Notocene rocks, which dip about 70° north-north-east. It appears that von Haast must have based the above description on beds some distance each side of the gorge, for on the river-banks the total thickness under the *Ostrea* bed does not exceed 40 ft. Park's account (1888) closely follows von Haast's, but in addition he records the presence of distinct plant-impressions from the shales—viz., *Fagus Ninnisiana*, *Phyllites eucalyptoides*, *Griselinia myrtifolium*, and a fragment of *Coriaria* (*Cinnamomum*?).

The succeeding *Ostrea* bed is about 20 ft. thick, and really consists of two or three shell-beds with sandy layers between. In places it consists chiefly of shells of *Ostrea*, in others of *Pugnellus*, and in others again of both of these, while there are a lesser number of other species of pelecypod. The upper part of the upper shell-bed is locally cemented by a calcareous cement in the shape of large poecilitic plates of calcite, and contains a few grains of glauconite and feldspar, in addition to the quartz of which it mainly consists. This is presumably the rock referred to by McKay (1877B) as "glance sandstone." The mollusca collected at this locality by McKay (1891) were determined by Woods (1917) as *Trigonia hanetiana* d'Orbigny, *Ostrea* sp. cf. *dichotoma* Bayle, and *Pecten* (*Camptonectes*) *hectori* Woods. In addition a species of *Cardium* is common, but does not appear to have been forwarded to Mr. Woods. Trechmann (1917) collected and described *Pugnellus waiparensis*.

Boby's Creek.—In Boby's Creek and its tributaries there are numerous sections of these beds, as they wrap round several inliers of the pre-Notocene rocks. I have not explored the area fully, and remain undecided whether or not there are two *Ostrea* beds represented. Where first seen, on going up Boby's Creek, the *Ostrea* bed is only about 2 ft. thick, and dips downstream. It rapidly thickens, as it rises on the sides of the cliffs up-stream, to about 6 ft., and is underlain by grey sands with a few carbonaceous streaks and many ironstone partings, and with occasional yellow efflorescence. After about 100 ft. these sands pass down into a lignitic series of interbedded carbonaceous shales and grey sands, also of considerable thickness. The section then becomes obscure for some distance. An *Ostrea* bed again reappears at the waterfall, but the beds below it have not been studied. In Bell's Creek, between the two gorges of pre-Notocene rocks, there is a lignite-seam which has been worked by former occupants of Onepunga Farm.

Von Haast (1871) describes the beds in Boby's Creek as rusty-coloured loose sands, similar to those in the Waipara River, followed by several seams of lignite and shale, about 10 ft. in thickness, some of them of better quality than those of the Waipara River. These in turn are followed by angular white quartzose sands, succeeded by the *Ostrea* bed. At the waterfall this consists mostly of complete specimens of the large *Ostrea*, but in other places the shells are more fragmentary, and in places the bed is replaced by calcareous sands.

The fossils determined by Woods from the *Ostrea* bed of Boby's Creek were "*Arca*" *hectori* Woods, *Trigonia hanetiana* d'Orb., and *Ostrea* sp. cf. *dichotoma* Bayle. In addition I obtained *Cucullaea* sp., *Cardium* sp., and *Pugnellus waiparensis* Trechmann (?).

A peculiar feature of the *Ostrea* beds, perhaps most marked in Bobby's Creek, is the strong smell of petroleum given out when the oyster-shells are freshly broken. I submitted specimens to the Dominion Analyst, but he reported that only a trace of petroleum could be determined analytically. The black colour of the oyster-shells and the odour of petroleum appear in New Zealand to be practically confined to the Piripauan *Ostrea* beds of North Canterbury.

McKay's Creek.—McKay collected in 1874 from the *Ostrea* beds of McKay's Creek, which is presumably one of the creeks entering the Waipara River from the north, above the limestone gorge, but he gave no detailed account of the beds in this locality. Woods determined from his collections the following species: *Nemodon* sp. and *Pecten* (*Camptonectes*) *hectori* Woods.

Birch Hollow (Plate XVII, fig. 1).—The beds below the *Ostrea* bed are much thicker to the north of the Waipara River, and are well exposed in Birch Hollow, at the upper end of the high terraces, where they form two large bluffs. They consist of a lower series of rotted conglomerates, 50 ft. thick; a middle lignite series of grey sands and carbonaceous shales, in places passing into lignite-seams, together about 100 ft. thick; and a higher series of yellow sands with ironstone partings, about 150 ft. thick. The *Ostrea* beds consist of a lower oyster-bed, 15 ft. thick, separated from a high similar bed, 1 ft. thick, by 20 ft. of sandstone. They contain *Ostrea* sp. cf. *dichotoma* Bayle and *Pecten hectori* Woods. The beds here are flatter than in the Waipara River, and strike north-north-east, with a dip of 15° east-south-east.

Weka Creek.—The *Ostrea* beds are well displayed in the Weka Creek, where they are about 40 ft. thick. At this locality I collected the specimens of *Ostrea* sp. cf. *dichotoma* Bayle figured by Woods, and he determined also *Pecten* (*Camptonectes*) *hectori* Woods from McKay's earlier collection. There are few other molluscs, but a fragment of a rhynchonellid was observed. The underlying rocks consist of loose white sands, 40 ft. thick, resting on 5 ft. of coal-shale, which here lies hard on the rotted argillite, and laterally dovetails into the sands.

The *Ostrea* bed is again seen as a thin band in the northern tributary of Weka Creek rising near Waikare, and may extend some distance to the north-west in the Waikare-Hawarden district. East of the Weka Pass these lower beds have not been observed, and they are certainly absent at the eastern end of the district.

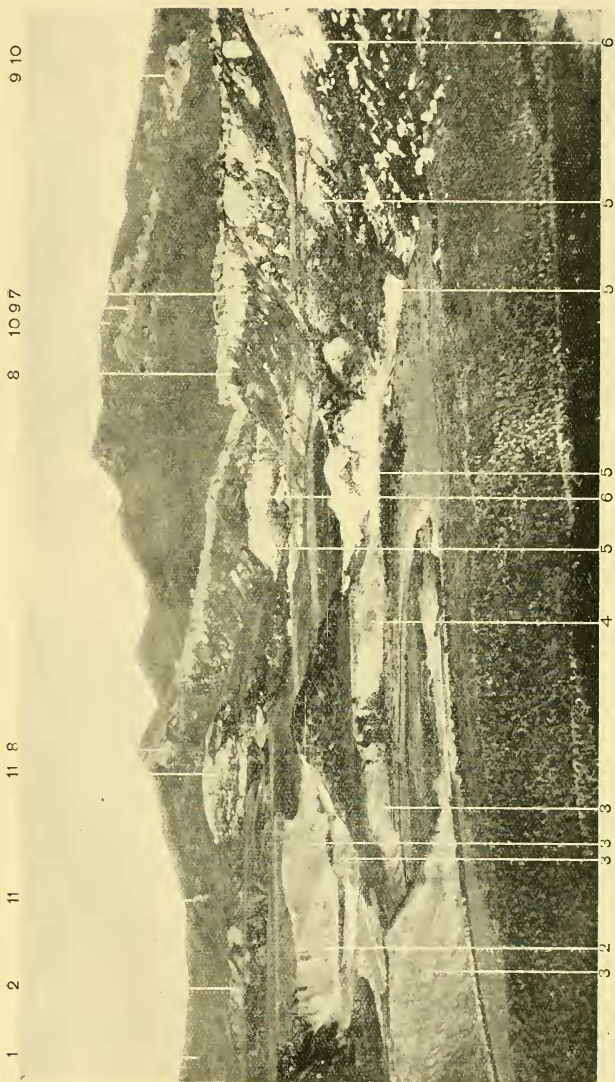
“Saurian Beds” and Waipara Greensands.

Waipara River.—An almost complete section of the beds between the *Ostrea* bed and the base of the Amuri limestone is exposed in the banks of the Waipara River between the Doctor's Gorge and the limestone gorge (Plate XVI). They consist of sands, mudstones, and greensands, and may be conveniently termed the “sulphur sands” and “sulphur mudstones,” together constituting the “saurian beds,” and the “Waipara greensands.” The sulphur sands and mudstones are so termed from the presence of a yellow efflorescence on the rocks, formed of sulphur compounds, combined with a distinct smell of sulphurous gases in the near vicinity of the cliffs and talus, particularly where these rocks are cut through by narrow gorges. The yellow efflorescence has not been chemically examined in the Waipara district, but a similar efflorescence on Clarentian mudstones in the Nidd Valley, near Coverham, has been reported on by the Dominion Analyst, who states,

"The encrustation contains a small quantity of free sulphur. The water extract showed the presence of ferrous sulphate and small quantities of calcium and magnesium salts." The efflorescence or encrustation is presumably due to the oxidation of sulphide of iron, present mostly in a state of fine division in the rocks, but partly in well-defined small nodular concretions. The name of "saurian beds" is given because of the presence of large concretions containing saurian bones in the upper part of the sulphur sands and the lower part of the sulphur mudstones. This is the horizon from which most of the Piripauan saurians have been obtained both in this district and at Amuri Bluff; but it should be noted that specimens have also been obtained both in the underlying coal-measures and in the overlying Waipara greensands. The latter rocks have usually been termed the concretionary greensands; but this name is unsatisfactory—first, because the concretionary beds compose only the lower part of the greensands, and, second, because there is a higher greensand horizon with true concretions to which the name might equally refer.

The *Ostrea* bed in the Waipara River is followed by clean white sands, containing a few carbonaceous shaly partings near their base. After about 100 ft. they become much more argillaceous, and pass finally into streaky rocks, forming grey cliffs, and consist, when freshly broken, of a dark mudstone matrix containing lighter-coloured streaks of glauconite and quartz sand in a calcareous base. At about 300 ft. above the *Ostrea* bed there is a thin band, about 6 ft. thick, consisting mainly of quartz sand and glauconite. This is succeeded by purple micaceous mudstones with a shaly parting, which are perhaps 200 ft. thick. The sulphur efflorescence commences after the first 50 ft. of sands, and continues in greater or less intensity throughout. Well-defined, nearly circular concretions, mostly from 4 ft. to 9 ft. in diameter, commence about 100 ft. above the *Ostrea* bed, and continue along certain planes for about 200 ft. (Plate XVII, fig. 2). Further similar concretions reappear in the middle and upper part of the purple mudstones. The concretions are formed of hard calcareous sandstone, and consist of grains of quartz with subordinate feldspar, glauconite, magnetite, and muscovite, set in a calcareous cement which is occasionally poecilitic, the individual calcite crystals being sometimes as much as an inch in diameter.

Fossils are not common in these concretions, but, owing to the keen search that has been made for saurian bones, a large number has been collected. McKay (1892) noted that out of a total of some 250 "boulders" examined only six or eight proved shell-bearing, and three were rich in shells. Usually in the shell-bearing concretion there is a mixture of monocotyledonous and dicotyledonous plant-remains. The pelecypods collected by McKay from this locality were determined by Woods (1917) as follows: *Malletia (Neilo) cymbula* Woods, *Trigonia waiparensis* Woods, and *Thracia* sp. In addition imperfect specimens of *Belemnites* were included, and gasteropods, which were sent to Professor Wilckens, of Jena, before the war, and have not yet been described. The Reptilia collected from the "saurian beds" in this vicinity by Hood, Holmes, von Haast, and McKay, as determined by Owen, von Haast, Hector, and Lydekker, were: *Leiodon haumuriensis* Hector, *Cimoliosaurus australis* (Owen), *C. hoodi* (Owen), *C. holmesi* (Hector), and *C. haasti* (Hector). Hood collected other specimens, which were lost in the s.s. "Matoaka," including bones which he judged to belong to *Teleosaurus*, but Hector (1874) considered it probable that the specimens should be referred to *Leiodon*.



View looking down the Waipara River towards the limestone gorge, with the Deans Range in the background. 1, pre-Notocone rocks of the Doctor's Range; 2, upper part of "saurian beds"; 3, lower (concretionary) Waipara green sands; 4, upper Waipara green sands; 5, glauconitic mudstones underlying Amuri limestone; 6, lower (marly) part of Amuri limestone; 7, upper (chalky) part of Amuri limestone; 8, Weka Pass stone; 9, lower Mount Brown limestone (C); 10, upper Mount Brown limestone (D); 11, slip composed mainly of Amuri limestone.



FIG. 1.—Looking down Birch Hollow, Middle Waipara. The lower cliff on the left shows the lignitic series, and the upper cliff the yellow sands of the Piripauan below the *Ostrea* bed.

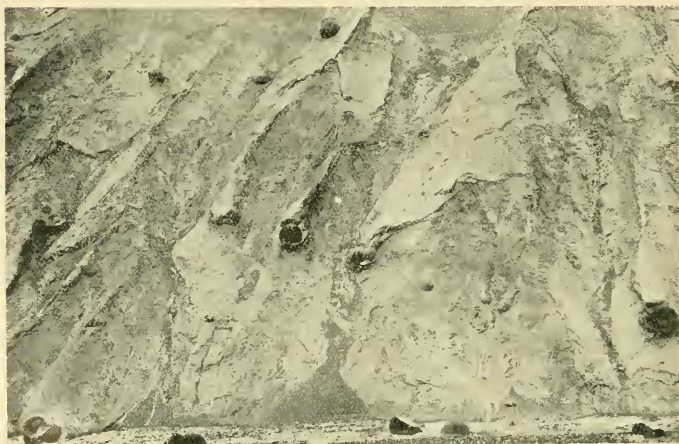


FIG. 2.—Grey muddy sandstones with saurian concretions, Waipara River.



FIG. 1.—Cliff of lower (concretionary) Waipara greensands, Waipara River.



FIG. 2.—View of the upper part of the Weka Pass. *a*, pre-Notocene rocks of the Moore's Hills block; *b*, Waipara greensands; *c*, Weka Pass stone surmounting Amuri limestone; *d*, Mount Brown beds in Mount Donald.



FIG. 1.—Cliff of Weka Pass stone overhanging Amuri limestone, Waipara River, near limestone gorge.



FIG. 2.—“Fucoids” in the Weka Pass greensand, cliffs overlooking Waipara River above limestone gorge.

The question was raised by Holmes (*cf.* Hector, 1869) whether the saurian "boulders" were not derived, or at least "deposited in the bed as rolled masses," since in some of them the saurian bones reach to the exterior, and appear there to be water-worn. Von Haast (1871) confirmed this observation, but concluded that the concretions were *in situ*. McKay (1892, p. 99) was therefore led to describe the boulders in great detail to explain this phenomenon: "They are often encased in 5 in. to 6 in. of impure cone-in-cone limestone, or by an envelope of similar thickness composed of sandy calcareous matter, preserving fucoid stems so abundantly that these must have formed a perfect envelope round the nucleus and greater mass of the concretion. Interior to this cone-in-cone or fucoidal covering the concretion is a hard greyish-blue limestone rock, and the remains of various species of saurians when present for the most part appear near the centre; but in cases in which considerable and connected portions of a saurian skeleton occur the bones are sometimes found through the whole diameter of the concretion proper, and into the cone-in-cone limestone or fucoidal envelope that surrounds the harder central portion. From the high cliff on the left bank of the river below the junction of Pirau Burn, concretions often fall into the channel of the river at its base, and in several cases, as at present can be seen, they leave embedded in the marly greensands one-half or less of the cone-in-cone, more rarely of the fucoidal, envelope; also boulders may be seen *in situ* from which one-half of the cone-in-cone envelope has been loosened and fallen off, leaving the concretion beneath perfectly round and smooth. When the calcareous matter accreting to form the boulder has from any cause been insufficient to include the whole of the remains within the concretion proper, some of the bones are fractured or jointed along the line joining the boulder and its envelope, and the bones thus appearing at the surface are polished as though the boulder had been formed mechanically, and transported to the position it now or lately occupied by the action of running water."

In the creek called by McKay the Pirau Burn the sands immediately above the *Ostrea* bed are well bedded by the interposition of numerous carbonaceous shaly partings, and present a great similarity to the sands under the *Ostrea* bed farther to the north-east.

The sulphur mudstones forming the upper part of the "saurian beds" are followed by the Waipara greensand, which may here be divided into a lower and an upper group. The lower group consists of 75 ft. of alternating hard and soft greensandstones, the hard bands being 1 ft. to 2 ft. in thickness and an average of 7 ft. apart. The hard parts are not continuous, but have a concretionary appearance (Plate XVIII, fig. 1). They have generally been described as calcareous, but show little effervescence with acid, and in thin section are found to consist of rounded grains of quartz and glauconite, accompanied by small pyritized fragments of organisms (probably radiolarian), set in a fine-grained granular matrix which is not birefringent. In hand-specimens the rock is mottled green and purple-grey. The upper group, 110 ft. thick, consists of softer, very dark greensands with a good deal of argillaceous matter and frequently with a shaly parting. In the cliff on the south side at the upper end of the large river-meander these pass quite gradually into the succeeding glauconitic mudstones, but in the cliff on the north side at the junction with Birch Hollow there are a few bands of hard greensandstone at the top, similar to those of the lower series. These upper greensands contain many pyrite concretions and have a marked yellow efflorescence.

Fossils are very scarce in the Waipara greensands, the most common being an obscure form from the lower group which has defied recognition. They consist of calcareous tubes, $\frac{1}{2}$ in. to 1 in. in diameter and a few inches in length, the interior being filled with matrix. Von Haast (1871b) recorded the presence of "some shells which appear to be allied to *Radiolites*," and the specimens he collected are preserved in the Geological Survey collections. They resemble the calcareous tubes collected by me, but are distinguished by the presence of nodal-like marks at intervals, giving the specimens an external resemblance to an equiset stem. Dr. Marie Stopes, who kindly examined the series of specimens, writes that they are certainly not Equisetinean or structures of any higher plant, and that Professor Garwood, who also carefully examined them, concluded that they were not algal; she showed them also to specialists working on lowly animals, but none of them would claim them, and the consensus of opinion was that they were inorganic. Von Haast (1871a) recorded also from the lower group "*Waldheimia lenticularis* and some pieces of a *Pecten* too small for recognition," and from the upper group two small *Pecten*s, *Waldheimia lenticularis* and *Scaloria browni* (?). Park (1888) recorded a *Waldheimia* and a *Pecten* from the lower group. Unfortunately, none of the above fossils are preserved in the Geological Survey collections. McKay (1877a) collected bones of *Cimoliosaurus australis* in a detached mass of greensand near the junction of Birch Hollow with the Waipara River, and in 1913 I obtained part of a saurian jaw with teeth in a hard band near the top of the upper group at the same locality. These two saurian occurrences serve to unite the Waipara greensands with the saurian beds in the Piripauan. There is every appearance of conformity, however, with the succeeding group.

Birch Hollow.—The sequence of the "saurian beds" and Waipara greensands in Birch Hollow is essentially similar to that in the Waipara River, but owing to the flatter dips, and the slipping of the sides of the narrow gorge, the thickness of the beds cannot be easily estimated. The creek is nearly choked below the *Ostrea* bed by the abundance of saurian concretions coming from the grey sandy mudstones. Many of these show saurian bones and a few are crowded with gasteropods, but are too hard to break with an ordinary hammer. A good collection of saurian remains could be made from this gorge if the difficulties of transport could be solved, but they are very considerable, as the sides form sandy cliffs nearly 200 ft. in height, while the bottom is choked for over a mile with fallen beech-trees and large boulders. The greensand bed separating the grey, streaky, sandy, concretionary mudstones below from the purple sulphur mudstones above is about 6 ft. thick, and is characterized by an abundance of small quartz pebbles of about $\frac{1}{8}$ in. diameter. The purple micaceous mudstones are well exposed in the main northerly tributary, which I did not explore, and appear to be upwards of 200 ft. thick. They do not appear here to bear any saurian concretions, and I noticed only one small concretion, of 4 in. diameter. The banded concretionary greensands do not appear to be more than 50 ft. thick, while the succeeding upper greensands at the mouth of the creek are perhaps thicker than in the Waipara River, and contain an abundance of pyrite nodules up to 3 in. or 4 in. in diameter. They are very dark, richly glauconitic, soft sandstones, with occasionally a tendency to assume a shaly parting, and in places have a very strongly marked sulphur efflorescence. From them I obtained a minute shark's tooth, considered by Mr. P. G. Morgan to be *Odontaspis* sp., and similar to *O. attenuata* (Davis).

Boby's Creek.—The “saurian beds” and Waipara greensands of the Boby's Creek watershed closely resemble those in the Waipara River. The *Ostrea* bed is followed down-stream by sandstones forming grey to light-yellow cliffs, and becoming more argillaceous when traced upwards, finally passing into grey sandy mudstones with marked yellow efflorescence. Saurian concretions commence a very short distance above the oyster-bed, but rarely exceed 4 ft. in diameter. Near the top these grey mudstones are notably streaky and inclining to be purple, and they are succeeded by a bed of loose sand about 20 ft. thick, which in turn is followed by similar streaky mudstones rapidly passing up into purple micaceous mudstones, which here abut against the fault. The higher beds appear on the high terrace on the south bank and up the most easterly tributary on this side, and consist of the concretionary greensands, the still higher beds not being exposed. The thicknesses of the above beds cannot be accurately estimated, as the bedding-planes are not well expressed, and the creek runs obliquely to the strike. In the upper part of Bell's Creek, besides the above rocks a small exposure of the upper Waipara greensands occurs. The whole series should be exposed in Boby's Creek above the waterfall, but I have not studied it there.

The following species of saurians, collected by Holmes, Travers, McKay, and von Haast, have been determined from the “saurian beds” of Boby's Creek: *Cimoliosaurus australis* (Owen), *C. haasti* (Hector), and *C. caudalis* Hutt. From Hector's collection of 1867, Chapman (1918) identified the following fish-remains: Teeth of *Scapanorhynchus subulatus* (Ag.) and of *Odontaspis incurva* (Davis), and vertebrae of *Lamna* (?). Presumably these are from the “saurian beds.”

Weka Creek.—The *Ostrea* beds are followed by loose sands of considerable thickness, which become more sulphurous and argillaceous in their upper part. The succeeding mudstones are harder than in the Waipara River, and in places are almost flinty and contain impure flint nodules a few inches in diameter. They are slightly micaceous, and are pale lilac on weathered surfaces, with rusty joint-planes and an occasional yellow efflorescence. These flinty mudstones present a great resemblance to Clarentian flinty mudstones in the Kekerangu and Benmore areas both in texture and colour. In their upper part they become less hard, and greyer in colour. No saurian concretions are seen either *in situ* or in the stream-gravels lower down, and are probably absent in this locality. The succeeding beds (Waipara greensands) are not here exposed, owing to a slip of Amuri limestone covering them.

In the northern tributary of Weka Creek rising near Waikare the hard bands of the Waipara greensands crop out at a number of points or form shoadings on the lower hills below the high cuesta of Amuri limestone and Weka Pass stone, and cross over into the Waikare watershed at the western end of Waikare Township. Thence the Waipara greensands extend as a narrow strip to the east between the township and the hills, but are partly covered by surface deposits of soft limestone and sands. Loose greensands are exposed in the excavations for the Waikare hospital site.

Weka Pass—Waikare Saddle.—Between the Waikare flats and the upper part of the Weka Pass the upper Piripauan beds are disposed in a flatly-dipping anticline around the western end of the ridge of pre-Notocene rocks which lies to the south of the Waikare Stream, and are exposed in the railway-cutting on the saddle near the 47-mile peg from Christchurch. The sides of this cutting are now considerably slipped and heavily grassed. Hutton (1885), who had an opportunity of examining this section soon after

the cutting was made, describes the beds, from below upwards, as bright-green argillaceous sands, calcareous green sandstone with shark's teeth, dark-grey micaceous sandy clay, and dark greensands. The dark-grey sandy clay passes in places into hard pale-lilac flinty mudstones similar to those observed in the Weka Creek.

East Side of Weka Pass.—In the valley entering the Weka Pass Stream from the east a little above the viaduct the hard bands of the Waipara greensands form a well-marked cuesta in the upper half of the valley, which continues over the saddle down to the upper part of Chasm Creek. The hard bands appear to be about 100 ft. above the pre-Notocene rocks, and about 300 ft. below the Amuri limestone and Weka Pass stone contact.

Chasm Creek and Omihi Valley.—In the lower part of Chasm Creek and the more easterly tributaries of the Omihi Valley the Waipara greensands are not exposed, owing to an overlap first of the Amuri limestone and underlying sands, and finally of the Weka Pass stone on to the pre-Notocene.

Waikare Valley.—About eight miles east of Waikare, Notocene rocks appear on the south side of the Waikare Valley and extend for some miles to the eastward. A continuous section of the beds below the Weka Pass stone is not exposed, but I observed in a small road entering the hills near what was Mr. Davy's farm that hard banded greensandstones, exactly similar to the lower group of the Waipara greensands, here form the base of the sequence, and rest directly on the pre-Notocene rocks. Higher up some loose sands were observed, but no typical Amuri limestone was seen, and the total thickness of the beds below the Weka Pass stone does not appear to exceed 100 ft.

KAITANGATAN.

Amuri Limestone.

The upper part of the Amuri limestone throughout the district is a glistening-white, hard, very fine-grained limestone, which is generally at the surface closely jointed into small cuboidal blocks. The lower part is more argillaceous and greyer in colour, and has a much coarser fracture. It passes down by imperceptible stages into a grey mudstone, and this in turn becomes a glauconitic mudstone with nests of glauconite distributed in an apparently capricious manner. This latter rock in the Waipara River rests with apparent conformity on the Waipara greensands, and much resembles the uppermost saurian mudstone immediately underlying the concretionary greensands. In the eastern end of the district, however, the glauconitic mudstones under the Amuri limestone rest on loose sands, which appear to be interposed between them and the Waipara greensands. For this reason, and because no distinctively Piripauan fossils have been found in them, they have been included with the Amuri limestone.

The microscopical characters of the Amuri limestone of Weka Pass have been briefly described by Marshall (1916A), who describes it as a pure *Globigerina* ooze: "The chambers of *Globigerina*, which are generally isolated, are fairly numerous. By far the greater part of the rock consists of very finely grained calcite." Near the contact of the Weka Pass greensand it "contains a considerable number of grains of quartz sand and some glauconite, as well as some brown mica."

A number of analyses of Amuri limestone from the Weka Pass have been published with a view to the comparison of its composition with that of pebbles in the Weka Pass greensand, or with that of the Weka Pass stone. These are collected in the following table, along with analyses of the latter rocks, and have been in part recalculated.

TABLE IV.—ANALYSES OF AMURI LIMESTONE AND WEKA PASS STONE.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
SiO ₂	..	7.25	14.45	11.12	7.52	6.74	..	..	..	..	..	..	..	..	22.51	34.95
Al ₂ O ₃	..	0.66	1.03	1.78	1.64	1.50	..	..	..	..	..	..	..	..	3.92	6.44
Fe ₂ O ₃	..	0.54	0.77	..	..	..	..	..	..	..	..	..	..	..	2.08	2.76
CaO	..	32.07	49.64	45.67	46.55	49.33	47.72	44.32	48.86	37.73	48.65	42.20	44.85	42.18	38.66	28.17
MgO	..	..	0.21	0.29	0.22	0.67	..	..	..	..	..	..	..	..	..	..
CO ₂	..	25.19	39.24	36.21	36.41	38.49	36.85	33.32	38.19	29.30	..	..	..	15.36	30.16	21.72
P ₂ O ₅	..	..	..	0.28	0.19	0.12	0.52	1.21	0.16	0.27	0.16	0.45	4.09	17.45	..	..
H ₂ O and organic	..	2.06	1.58	1.74	1.05	1.20	..	..	9.30	28.20	12.08	11.95	11.52	4.86	2.29	3.50
Insol.	..	..	..	..	..	..	11.75	16.97	..	..	..	..	..	5.79	..	..
Alk. and undet.	..	42.74	0.40	1.90	1.56	1.26	..	..	..	..	..	..	..	14.36	..	1.77
Sum ..	100.00	100.00	100.00	100.00	100.00	100.00	..	..	..	..	..	..	..	100.00	100.00	100.00
CaCO ₃	..	57.26	88.64	81.56	82.34	87.47	83.75	75.73	86.80	66.60	86.43	74.09	68.55	26.14	67.60	47.62
MgCO ₃	..	..	0.45	0.61	0.46	1.41	..	..	..	..	..	..	..	..	0.80	1.46
Ca ₃ (PO ₄) ₂	..	..	..	0.72	0.49	0.31	1.34	3.12	0.41	0.70	0.41	1.16	10.55	44.99	..	..

1 to 13, Amuri limestone; 14, Weka Pass greensand; 15, Weka Pass stone; 16, phosphatic concretion.

1. Right bank of Weka Pass Creek, near the railway-viaduct. McKay, 1887A.
2. Average sample from thickness of 40 ft. Park, 1905.
3. 2 ft. below Weka Pass greensand. Park, 1905.
4. At contact with glauconitic calcareous sandstone, in gorge of Weka Pass Stream above railway-viaduct. Morgan, 1915.
5. Uppermost layer in same locality as 4. Morgan, 1915.
6. Hard Amuri limestone, about 35 ft. below upper surface, in same locality as 4 and 5. Morgan, 1915.
7. Pebbles of Amuri limestone in glauconitic calcareous sandstone, same locality as 4, 5, and 6. Morgan, 1915.
8. Amuri limestone, near upper surface, same distance up valley of Weka Pass Stream above railway-viaduct. Morgan, 1915.
9. Amuri limestone, 30 ft. below upper surface, in same locality as 8. Morgan, 1915.
10. Amuri limestone, 50 ft. to 80 ft. below upper surface, in same locality as 8. Morgan, 1915.
11. Sample 2 ft. from present surface of Amuri limestone. Speight and Wild, 1918.
12. Sample from upper 6 in. of honeycombed portion of Amuri limestone. Speight and Wild, 1918.
13. Detached nodules of Amuri limestone lying in the Weka Pass stone a few inches above the present surface of the Amuri limestone. Speight and Wild, 1918.
14. Weka Pass greensand, 2 ft. above Amuri limestone. Park, 1905.
15. Average sample of Weka Pass stone broken from the whole thickness, Weka Pass. Park, 1905.
16. Phosphatic nodule from Weka Pass greensand. McKay, 1887.

It will be seen that the hard white limestone at the top consists of 80 to 88 per cent. of carbonate of lime and 14 to 6 per cent. of silica. The grey limestone 50 ft. to 80 ft. below the upper surface contains only 66 per cent. of carbonate of lime.

The Amuri limestone contains few microscopic fossils either within the district or elsewhere. In the small gorge above the viaduct in the Weka Pass I observed a small fragment of a *Pecten* about 25 ft. below the upper surface. Foraminifera constitute a fair proportion of the rock, and from a collection which I made from the uppermost 3 ft. in the above locality Mr. F. Chapman determined the following forms: *Guembelina globulosa* (Ehr.), *Bulimina obtusa* d'Orb., *Bulimina* sp. nov., *Globigerina cretacea* d'Orb., *Anomalina ammonoides* (Reuss), and *Pulvinulina elegans* (d'Orb.). From the same locality, 25 ft. to 30 ft. below the upper surface, he determined *Nodosaria annulata* Reuss, *Globigerina bulloides* d'Orb., *Anomalina ammonoides* (Reuss), and *Pulvinulina elegans* (d'Orb.). These forms, he considers, establish the Danian age of the rock.

The underlying glauconitic mudstones yield Foraminifera, Ostracoda, fish-scales and vertebrae, and fragments of molluscs and brachiopods. The fossiliferous nature of this horizon has only recently been established, and the specimens, excepting the brachiopods, have not been examined by specialists. The brachiopods include a species of *Aetheia* hardly distinguishable from the Oamaruan *A. gaultieri*. The remainder bear no resemblance to Oamaruan species, and include a new genus of Terebratulid. I hope to describe these and other Cretaceous brachiopods in the near future.

Waipara River.—The best section through the Amuri limestone is that afforded by the banks of the Waipara River at the Limestone Gorge and on the south bank for some distance above it. The following beds are exposed :—

Hard, white (chalky), closely-jointed limestone, including	Feet.
a few marly bands near the base	100
Softer, grey, argillaceous (marly) limestone with coarser bedding and jointing	60
Grey mudstone, passing down into dark blue-grey streaky mudstone, with nests and streaks of glauconite	300

The upper white limestone is thin-bedded and closely jointed in all directions. It forms nearly vertical cliffs, passing below into grassy talus-slopes. The grey limestone is thicker-bedded and less jointed, and has a spheroidal weathering like a mudstone. It is sometimes known as the "fucoidal limestone," from the presence of a peculiar fossil (?) known as the Amuri "fucoid," shown in fig. 5. This consists of rudely conical masses of limestone, with the apex of the cone directed upwards, the diameter of the base ranging from a few inches up to 3 ft. From the apex of the cone coarse flutings radiate to the exterior, the flutings being rounded on the bottom, and the intervening ridges rounded or angular according to the shape of the flutings. The surfaces on which the latter are developed are not strictly conical, but sometimes almost spiral, as in the figure. Occasionally the flutings bifurcate. The "fucoids" occur chiefly in the main mass of the grey marly limestone, but are best displayed in a marly band, about 18 in. thick, 10 ft. above the base of the white limestone. Besides the "fucoids" the grey limestone contains numerous Foraminifera and many small chitinous flakes. It was to a small fragment of the Amuri "fucoid," labelled "Culverden," but more probably from the Waipara or Amuri Bluff, that Hutton gave the name of *Pinna plicata*.

The mudstones down into which the grey limestone passes are variable rocks, being in places ordinary dark-grey mudstones, in others very glauconitic mudstones, but for the most part consisting of a mudstone matrix, blue when freshly broken, white when weathered, containing small and large nests of glauconite in large grains. They thus resemble considerably the saurian sandy mudstones, but are more argillaceous and glauconitic. There appear to be about 300 ft. of these beds above the large river-meander on the south bank, and probably a greater thickness between the mouth of Birch Hollow and the limestone gorge on the south side. Foraminifera are abundant throughout, but are mostly rotted. Shell-fragments are present in a few places, while fish-scales and vertebrae and obscure plant-remains are fairly frequent. In the cliffs on the north bank of the river below Birch Hollow crushed tubes of *Teredo* are not infrequent, but no other shells were obtained. From a cliff on the east side of the small creek on the right bank I obtained a number of fragments of brachiopods. It is eminently desirable that as complete a collection as possible should be made from this horizon.

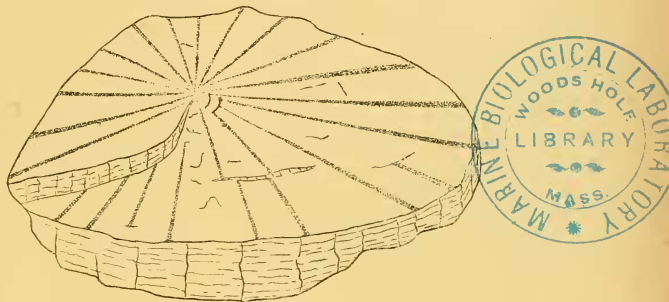


FIG. 5.—The Amuri "fucoid."

Bell's Creek, Boby's Creek.—In the upper part of Bell's Creek, and in a small tributary which has cut a gorge through the Amuri limestone, the lower, grey limestone and the underlying glauconitic mudstones are exposed in a number of small cliffs, not furnishing a connected section. The glauconitic mudstones resemble those in the Waipara River, and contain large and small Foraminifera, fish-scales, and various spines and spicules, but no shells were obtained except a single fragment of a brachiopod. Near the base these rocks contain numerous rounded white and green quartz pebbles up to $\frac{1}{8}$ in. diameter, and small rounded pieces of retinite up to $\frac{1}{2}$ in. diameter.

Weka Creek.—The Waipara greensands are not exposed in the main branch of Weka Creek, owing to a slip of limestone overlying them, and the succeeding glauconitic mudstones are also mostly obscured. The upper 12 ft. of the latter bed is exposed in the cliffs of a small creek entering from the west just above the limestone gorge, and consist of dark mudstones with nests of glauconite similar to that below the Amuri limestone in the Waipara River. They are directly succeeded by the marly limestone, of which about 30 ft. is exposed. The same mudstones occur in the bed of the Weka Creek at the junction of this tributary, and yield fish-scales and vertebrae and Foraminifera.

Weka Pass.—The exposures of the lower part of the Amuri limestone are not very good in the Weka Pass. Morgan, (1915) has noted the following sequence:—

- (1.) Amuri limestone, fairly pure, 40 ft. or less in thickness. This is much jointed and even shattered in places.
- (2.) Amuri limestone, argillaceous, about 40 ft. thick. This rock where exposed to weathering breaks into small cuboidal or irregularly-shaped fragments.
- (3.) Calcareous light-grey claystone, probably between 40 ft. and 50 ft. thick. Exposed surfaces break into very small fragments.
- (4.) Uncemented sand, with lumps of clay.

Waikare.—An important exposure has recently been made by the excavation for soft (surface) limestone in Trounce's pit, a mile west of Waikare. This pit lies on the grassy slopes below the outcrop of the outlier of Amuri limestone, and has passed through the surface deposit of soft limestone into a tough glauconitic mudstone, which exactly resembles those below the Amuri limestone at Weka Creek and the Waipara River. Mr. B. C. Aston has determined the carbonate of lime as 10 per cent. It contains numerous Foramanifera and rare sharks' teeth and brachiopods, including *Aetheia* sp. cf. *gaulteri*.

From borings made in the grassy slopes below the pit, and from the presence of springs farther down, it appears that the above mudstone rests on glauconitic sands, which in turn rest on some impermeable bed, along the top of which a series of springs appears.

Omihi Creek.—North-north-east of Mount Donald the Amuri limestone and underlying rocks are exposed in a small dry gorge tributary to the main tributary of the Omihi Creek. The lowest beds exposed are about 60 ft. of yellow sands, mostly fine-grained but with a fair proportion of large well-rounded quartz grains and much white mica. These become glauconitic and harder 3 ft. from the top, and are succeeded by 15 ft. of glauconitic mudstone, which passes up into 5 ft. of fucoidal argillaceous limestone with a good deal of glauconite. This is succeeded by the concretionary band of the Weka Pass stone, here about 6 ft. thick, which in turn is followed by 40 ft. to 50 ft. of typical Weka Pass stone.

The sands at the base are well exposed farther up the main tributary of the Omihi Creek, and rest upon the Waipara greensands.

Farther east, although there are no clear exposures, the beds between the Weka Pass stone and the pre-Notocene rocks greatly diminish in thickness, and it is probable that no Amuri limestone exists. East of Moore's Hill South the beds below the Weka Pass stone again increase in thickness, and near Davy's farm sands similar to those described above are seen between the Waipara greensands and the Weka Pass stone.

OAMARUIAN.

Weka Pass Greensand and Weka Pass Stone.

The "Weka Pass stone" is an old quarryman's name for the building-stone of the Weka Pass, and was introduced into geological literature by Hutton (1877), who included under it not only the limestone, formerly used as a building-stone, but also the calcareous greensandstone down into which the limestone passes. McKay referred to the latter rock as the "greensand conglomerate," while Speight and Wild termed it the "nodular

band" or "layer." Since it is not always nodular within the district, but is always more glauconitic than the overlying limestone, it is admissible to name it the "Weka Pass greensand," and to confine the name of "Weka Pass stone" to the overlying limestone. There are thus two greensand horizons both in the Weka Pass and the Middle Waipara—viz., the Waipara greensand below the Amuri limestone, and the Weka Pass greensand resting on the Amuri limestone. There is a third greensand horizon in the Waipara River—viz., a facies of the "grey marls" resting on the Weka Pass stone.

The Weka Pass stone is an arenaceous, slightly glauconitic limestone, 50 ft. to 100 ft. thick, the calcareous part of which is composed of the tests of Foraminifera and a fine-grained base similar to that of the Amuri limestone. In some parts, where the terrigenous elements are feebly developed, the rock becomes almost indistinguishable from the Amuri limestone, and, like it, is then thin-bedded and closely jointed, but for the most part it is coarser in texture, is cream-coloured instead of white, and is thick-bedded and not closely jointed. Consequently it presents, as Morgan (1915) pointed out, a more massive appearance in natural exposures than the Amuri limestone. Its chemical composition is shown in Table IV, consisting mainly of 67 per cent. of carbonate of lime and 22 per cent. of silica, whereas the Weka Pass greensand contains only 47 per cent. of carbonate of lime and 35 per cent. of silica. The Weka Pass greensand, being a softer rock than the two limestones it separates, is generally hollowed out, and the Weka Pass stone overhangs the hollow in a massive rounded ledge (Plate XIX, fig. 1). Where the Amuri limestone below is also cliffed the hollow of the greensand makes a marked break in the cliff, which is often occupied by a sheep-walk. Along certain parts of the outcrop the Weka Pass stone is apparently weaker towards erosion than the Amuri limestone, and instead of overhanging it in a cliff, as is usually the case, forms a small cuesta at the foot of the dip-slope of the more prominent Amuri limestone cuesta. This is the case between Onepunga Farm (to the south of Bobby's Creek) and Mount Grey, and for a short distance north-east of the North Dean. At Onepunga the Weka Pass stone is rather more glauconitic than usual, and Speight and Wild have suggested that this and the greater abundance of phosphatic nodules are evidence that the old shore-line is being approached. More direct evidence would be an increase in the percentage and grain-size of the terrigenous material; and, as this is wanting, the suggestion lacks weight, more especially as the confirmatory evidence of overlap of the lower beds is absent in this locality.

The Weka Pass greensand presents two facies. In a few localities it is a simple slightly glauconitic calcareous sandstone presenting no peculiarities. This is particularly the case in the middle part of the limestone cliffs south of the Waipara River, between the road leading down from the Ram Paddock to the river and the limestone gorge. Lenticular masses of glauconitic material appear in the upper part of the Amuri limestone, and these gradually increase in number and size until the whole mass becomes glauconitic, and after a few feet passes insensibly into the Weka pass stone. At this locality "fucoïds" are abundant in the upper part of the greensand (Plate XIX, fig. 2), including a peculiar type with curved transverse divisions like the septa of an *Orthoceras*, but unsymmetrical.

Elsewhere the Weka Pass greensand presents a very peculiar contact towards the Amuri limestone, a contact which has been repeatedly claimed as unconformable and with which a very considerable proportion of the literature on the district has been concerned. Little can be added to the

detailed descriptions by Morgan (1915, 1916) and the exhaustive discussion by Speight and Wild (1918). The upper beds of the Amuri limestone are not compact, but consist of small separated blocks of white limestone, a few inches in diameter, in the interstices of which there occurs a filling of calcareous greensand of the same nature as the overlying bed of greensand. The upper 1 ft. or 2 ft. are most affected, but the penetration of the limestone by the greensand occasionally reaches a depth of 6 ft. The blocks of limestone are mostly irregular in outline, and similar in shape to the cuboidal blocks isolated by jointing throughout the limestone. Morgan describes the fissures between the blocks as irregular cavities, following joint-planes to a great extent, but evidently enlarged by chemical erosion or solution, and mentions the existence of small peninsulas of limestone, some of which are joined only by a narrow neck to the main mass, extending several inches upward into the glauconitic sandstone. Speight and Wild describe the Amuri limestone as "jointed into flaky quadrangular blocks, the upper 2 ft. or more being bored by marine worms and the casts filled with glauconitic sandstone. The amount of boring increases progressively upwards until what may be called the transitional layer is reached." When I first examined the contact, in 1912, I noted occasional borings with round sections in the limestone, filled with glauconitic calcareous sandstone, but I formed the impression that the greater part of the penetration of the limestone by the greensand had taken place along joint-planes enlarged by solution, and after re-examining the contact with Speight and Wild's explanation in mind I am still of the same opinion, and agree with Morgan. I noted also in the gorge of the Weka Pass Stream above the viaduct that 5 ft. below the contact, where the limestone is practically undisturbed, there are occasionally bedded lenticular masses of glauconitic calcareous sandstone within the limestone. Speight and Wild observed a similar phenomenon in the Weka Creek, where they describe the limestone as breaking into quadrangular blocks, with interstitial calcareous greensand in layers parallel to the bedding in its upper portions, very occasional burrows extending to 6 ft. below the actual junction.

The uppermost part of the Amuri limestone, termed by Speight and Wild the "transitional layer," they describe as follows: "This consists in its lower part of Amuri limestone material thoroughly bored, with the interstices filled with glauconitic limestone. The result of the boring increases progressively, and the quantity of glauconitic material increases *pari passu*. The upper 6 in. is completely bored, so that peninsulas of Amuri limestone project at times into the overlying glauconitic layer, and at times become detached and resemble subangular pebbles in appearance. They are more phosphatic than the underlying limestones, and the included glauconitic limestone is more phosphatic than the overlying glauconitic layer. Included in this band are small angular nodules, green or black in colour, which are strongly phosphatic. Very occasionally small well-rounded pebbles of quartz, about $\frac{1}{4}$ in. in diameter, are met with."

The lowest layer of the greensand, described in the last part of the above extract, is termed by Speight and Wild the "nodular layer." The great majority of the inclusions are subangular pieces of Amuri limestone, slightly phosphatized, and the true phosphatic concretions are relatively scarce and quite small. The limestone inclusions are most abundant in the lower 12 in. of the greensand, but occur sporadically up to 2 ft. from the base, and are then, according to Morgan, mostly rounded. In addition to the quartz pebbles noted in the Weka Pass, Speight and Wild record a well-rounded

pebble of greywacke near Bobby's Creek, while Morgan records one or two very small pebbles of greywacke, together with a small rounded phosphatic lump, probably a fragment of bone. I have obtained from various localities rounded quartz pebbles up to $\frac{1}{2}$ in. diameter, a subangular pebble of quartz-schist 1 in. long, and flattened pebbles of schistose greywacke over 1 in. in diameter. The upper part of the greensand passes by an increase of its calcareous content quite gradually into the Weka Pass stone.

The Weka Pass stone and greensand contain fossils only sparingly, the chief horizon being at the transition bed of the two rocks, on the underside of the overhanging bluffs so commonly developed. The richest locality for fossils is at Onepunga.

Cetacean bones occur fairly commonly, but are rarely perfect. I obtained an ear-bone of a whale from Onepunga. Sharks' teeth are fairly widespread, and I collected the following: From Onepunga, *Isurus desori* and *Lamna apiculata*; north-west of Mount Brown, *Odontaspis elegans*; cliffs overlooking Waipara River, *Isurus retroplexus*, *I. desori* (identified by Mr. P. G. Morgan). In addition Chapman identified the following species, believed to come from the Weka Pass stone, though the exact locality is uncertain: *Odontaspis incurva*, *Odontaspis* sp., *Isurus desori*, *Carcharodon megalodon*, and *Scombroclupea* cf. *macrophthalmus* (Heckel). The specimen of *Carcharodon megalodon* was labelled "Bobby's Creek," and Chapman states that he examined the matrix, and had no hesitation in stating that it came from the Weka Pass stone. There is, however, no outcrop of this rock in the main branches of Bobby's Creek, though the specimen may have come from the slopes of Mount Brown.

Of molluscs, *Pecten huttoni* and *Epitonium lyratum* are the most abundant, and occur in the cliffs overlooking the Waipara River, north-west of Mount Brown, at Onepunga, in the Weka Pass, and in the upper part of the Weka Pass Stream. At Onepunga I obtained in addition *Struthiolaria spinosa*, *Euthria media* (Hutt.)?, *Voluta* sp. cf. *protorhysa* Tate, *Turris altus*, *Dentalium solidum*, *Limopsis aurita*, *Teredo heaphyi*, and indeterminable species of *Aturia*, *Polinices*, *Architectonica*, *Pleurotomaria*, *Trochus*, and *Ostrea*. From the cuesta between the Deans and the Waipawa River I obtained the holotype of *Lima imitata* Sut., and on the opposite side of the river observed casts of ribbed *Pectens* on the back slope of the cuesta.

Of brachiopods, *Aetheia gaulteri* is most widespread, being found at Onepunga, between the Deans and the Weka Creek, and in the upper part of the Weka Pass Stream. *Pachymagas cottoni* n. sp. has been obtained from Onepunga and the cliffs overlooking the Waipara River. *P. huttoni* has been collected at Onepunga.

Foraminifera are fairly abundant as isolated large examples at many localities, while smaller species occur throughout the rock. From a collection made in the small gorge above the viaduct in the Weka Pass Mr. F. Chapman has identified (*inter alia*) *Clavulina antipodum* Stache, *Polymorphina lingulata* Stache, and *Truncatulina thiasa* (Stache). From an examination of these and other Foraminifera and the sharks' teeth he considers that the rock is probably Eocene.

Echinoid fragments and spines are common at many localities, and *Graphularia* sp. and casts of other corals are found at Onepunga.

Hutton (1885 B, c) recorded a large number of fossils from the Weka Pass stone, including many of those mentioned above. The additional species (in modern nomenclature) are: *Scaphella elongata*, *Voluta attenuata* (cf. *V.* sp. cf. *protorhysa*, above), *Epitonium rotundum*, *Galeodea senez*, *Pleurotomaria*

tertiaria, *Aturia ziczac* var. *australis*, *Lima laevigata*, *Pecten williamsoni*, *P. fischeri*, *P. beethami* var. B; beside brachiopods, echinoids, corals, and sharks' teeth, in which Hutton's identifications cannot be so safely accepted. Unfortunately, many of the older collections in the Canterbury Museum are labelled simply "Weka Pass," without reference to the exact horizon. It is possible that the species he identified as *Lima laevigata* should be *L. imitata*, which resembles it in size.

The Weka Pass stone presents little variation in composition and thickness throughout the district. Morgan estimates it at 100 ft. thick in the Weka Pass Stream. Usually it is not so thick, the average being perhaps 60 ft. It succeeds the Amuri limestone everywhere this is developed, but in the tributaries of the Omihi Creek east of Mount Donald it overlaps the Amuri limestone and rests directly on the greywackes of the Moore's Hills block. No actual exposure of the junction can be seen, but there is a small, flat-lying outlier lying off the second V outcrop uphill east of Mount Donald, and near the top of a road leading from the Waikare Valley, which approaches within 20 yards of an outcrop of greywackes, with only a few feet difference in level, so that not more than 20 ft. of beds can separate the two rocks. The neighbouring greywacke surface has all the characters of a recently stripped fossil peneplain. The Weka Pass stone in this neighbourhood is more glauconitic than usual, with fairly numerous dark phosphatic concretions, and has a peculiar pencil-like or thumb-like fracture.

The "Grey Marls" and Mount Brown Beds.

The beds following the Weka Pass stone have long been known as the "grey marls" and the Mount Brown beds, and the conformity or unconformity of these two sets of beds has been much canvassed, but there has been no close definition of what is to be included in these two series. "Grey marls" by common consent include any mudstone between the Weka Pass stone and the overlying limestones, which also by common consent are included in the Mount Brown beds; but between these two limits there is also a considerable thickness of sands and sandstones; and, moreover the upper limit—viz., the lowest limestone of the Mount Brown series—is not a persistent lithological horizon in the district. It will therefore be convenient to describe these two "series" together.

Five limestones must be distinguished in the Mount Brown series, and may be conveniently indicated by the letters A, B, C, D, and E. The lowest, A, forms a cuesta on the Ram Paddock, and also on the watershed between Bobby's Creek and the Kowhai River, towards Mount Grey. It is a white polyzoan impure limestone containing in places an abundance of large cup-shaped Polyzoa, and is the "white and yellowish calcareous sandstone" of Hector (1869), and the "Bryozoa beds" of Haast (1871). The succeeding limestones, except the last, are mostly reddish-brown rubbly arenaceous limestones, the calcareous matter being largely comminuted shells of various marine organisms. Polyzoa, barnacles, or brachiopods in places constitute the greater part of the limestones, and there are also molluscan shell-beds. The second, B, forms the lower of the two limestone cuestas on the south-east side of the Weka Pass, and contains few fossils except small cup-shaped Polyzoa and barnacles. It may possibly be the same as the third, C, which forms the lower band on the cliffs overlooking the Waipara River below the limestone gorge, and is characterized by the presence of the brachiopod *Magadina waiparensis* Thomson. The fourth, D, is the main band throughout the district, occupying the

top of the ridge overlooking the Weka Pass, the greater part of the skyline between the Weka Creek and the Waipara River, and the summit of Mount Brown. It contains a rich brachiopod fauna, the commonest species being *Magadina browni* Thomson, *Pachymagas parki* (Hutton), and species of *Rhizothyris*. The uppermost limestone, E, forms the cuesta south-east of the main band, D, at the approach to the Weka Pass, and is characterized by the brachiopods *Neothyris novara* (von Ihering) and *Stethothyris sufflata* (Tate).

Middle Waipara, South of Bobby's Creek Fault.—Starting at the western end of the district, in the tributary of Bobby's Creek rising near Mount Grey, the Weka Pass stone passes up gradually into grey mudstones, the typical "grey marls," which are here apparently 200 ft. to 300 ft. thick. They yielded *Verconella costata*, *Malletia australis*, *Limopsis aurita*, *Pecten huttoni*, and *Diplodon zelandica* (Gray) ?. Above these the section is not clear, but there are sands containing *Turritella* and *Malletia*. The watershed between Bobby's Creek and the Kowhai River is here occupied by a cuesta of the lowest Mount Brown limestone, A, which is a white polyzoan limestone, about 50 ft. thick. It yielded *Pecten huttoni*, fragments of a ribbed *Pecten*, and *Pachymagas clarkei* n. sp. The higher Mount Brown limestones were not here studied.

In Mount Brown two bands of reddish-brown limestone may be distinguished. The lower, B, is not richly fossiliferous, but has yielded *Anomia trigonopsis* and *Pecten palmipes*. Bed C has not been identified, but the upper band, D, forming the summit, is thicker than usual. Fossils are scarce near the summit on either side, but in the cliffs overlooking the Waipara River, where over 100 ft. of limestone is exposed, there is a very persistent band, formed mainly of *Magadina browni*, near the top. From some holes at the base of the cliff I obtained an abundance of *Bouchardia minima* Thomson, besides *Magadina browni*, *Pachymagas McKayi* n. sp., *Anomia trigonopsis*, *Pecten williamsoni* Zittel (?), *P. zelandiae*, and *Lima colorata*.

Middle Waipara, North and North-east of Bobby's Creek Fault.—On the northern side of the Bobby's Creek fault, in the north branch of Bobby's Creek, the Weka Pass stone passes up gradually into grey mudstones, about 60 ft. thick. These are followed by a considerable thickness of soft sandstones, separated into upper and lower divisions by a thin bed of mudstone containing *Mopsea* sp. and Foraminifera. The upper sands are cut off by the fault.

The most complete section is that afforded by the banks of the Waipara River below the limestone gorge, and partially repeated in the lower part of Bobby's Creek owing to folding. The section is continued in the higher slopes to the east up to the horizon of the main Mount Brown limestone, and includes the following beds:—

	Feet.
Main Mount Brown limestone (D)	60
Loose yellow-brown sands	80
Third Mount Brown limestone (C)	30
Bluish muddy sandstones with concretions, passing down into polyzoan shelly beds and a grit at the base ..	200
Mudstones with thin sandstone intercalations ..	200
Whitish sandstones with thin mudstone intercalations..	200
Glauconitic mudstone	25

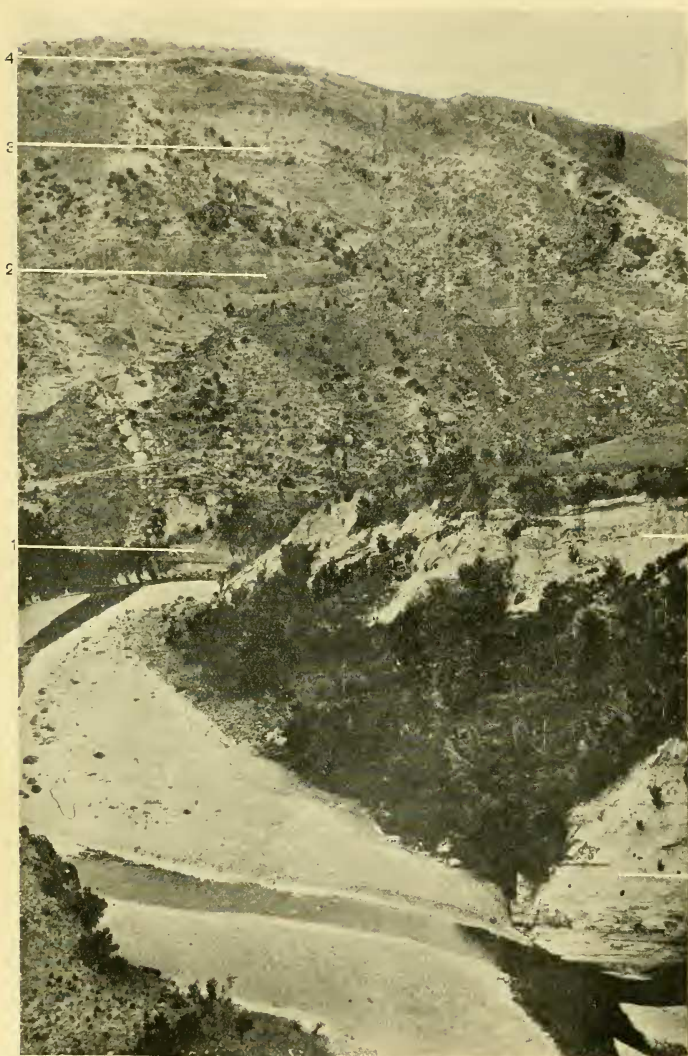
The Weka Pass stone becomes glauconitic at its top, and passes quite gradually into glauconitic mudstones. The succeeding sandstones are in beds of 4 ft. to 10 ft., separated by mudstones 6 in. to 2 ft. thick. Some of the sandstones contain small rounded pebbles of foraminiferal calcareous sandstone, suggesting derivation by erosion from the Weka Pass stone. In the higher beds the sandstones are in thinner layers and the mudstones thicker. Fossils are scarce throughout, and so tender as to be very difficult of collection. *Epitonium zelebori* was obtained low down in the sandstones. Two shelly beds were noted on the right bank of the river, below the grit, both containing *Pecten huttoni*, the higher being similar to the polyzoan beds above the grit. The latter rock contains small pebbles of greywacke. It is succeeded by alternations of thin polyzoan limestones and bluish sandstones, and the latter beds continue to the base of the third Mount Brown limestone (C), and contain poorly defined concretions with shells and plant-remains (Plate XX). Just above the polyzoan beds I obtained *Paphia curta* and a fine specimen of *Pecten beethami* var. B Hutt.

Part of the above sequence is repeated in the lower part of Boby's Creek, north-east of the fault, and in the banks of the Waipara River above and below the junction of Boby's Creek. The cuesta of the lowest Mount Brown limestone (A) on the Ram Paddock is composed of a whitish polyzoan calcareous sandstone, consisting chiefly of larger cup-shaped and smaller Polyzoa, and yielding fairly numerous but poor specimens of *Pachymagas clarkei* n. sp., with rare pectens and echinoids. The limestone thins out rapidly along its strike in both directions, and obviously formed a polyzoan reef or shoal in the Oamaruan sea. To the west-south-west it crosses the Natural Bridge Creek, greatly diminished in thickness, just above the natural bridge, but does not continue to the east-north-east as far as the banks of the Waipara River. It apparently thins out also in the direction of its dip (south-south-east), but is presumably represented by the polyzoan beds near the bottom of Boby's Creek and those above described in the Waipara River.

In the Natural Bridge Creek, and in Boby's Creek below it, there is some gentle folding, so that a continuous section is difficult to trace. The polyzoan beds appear to be the lowest horizon exposed, and are succeeded by bluish muddy sandstones yielding *Anomia trigonopsis*, *Pecten beethami*, *Pecten huttoni*, and *Nucula sagittata* Sut., the latter species being first described from this locality. These are succeeded by current-bedded sands, on which a cream-coloured sandstone rests unconformably.

At the time of my first visit, in 1912, a recent slip had exposed a very clear unconformity on the side of the bluff facing the Waipara River at the upper corner of the junction between Boby's Creek and the river (fig. 6). The rocks below and above the surface of the contact were of similar nature—viz., bluish muddy sandstone—but those below were not so clearly bedded. The upper beds contained pebbles and boulders of the same nature, and also of grey mudstones and of greywacke, as well as broken shells. This section had become obscure at the time of my visit in 1913. A short distance up the Waipara River, on the same bank, I observed some shell-beds, which must lie above the unconformity, containing casts of *Cucullaea*, ribbed Pectens, a large *Dentalium*, and many gasteropods.

The lower part of the "grey marls" is exposed on the back of the cuesta of Weka Pass stone between the limestone gorge of the Waipara River and the saddle north-west of the North Dean. Here 50 ft. of grey mudstone follows the Weka Pass stone with every appearance of complete



View across Waipara River below limestone gorge. 1, bluish-grey sandstones; 2, lower Mount Brown limestone (C); 3, yellow-brown sands; 4, main Mount Brown limestone (D).



FIG. 1.—Syncline in the main Mount Brown limestone (D), Waipara River, north-east side below Boby's Creek.

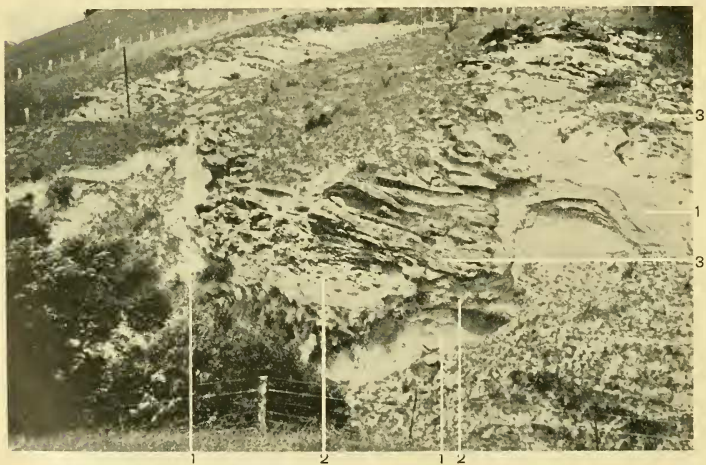


FIG. 2.—Cliff in Weka Pass Stream, below railway-cutting, 43 $\frac{3}{4}$ miles from Christchurch. A fault with downthrow to the left intersects the cliff. 1, grey sandstone (top of "grey marls"); 2, hard calcareous conglomerate with shells; 3, lower Mount Brown limestone (B).

conformity. Fossils are fairly plentiful, including corals and Foraminifera, but the molluscs are mostly in the condition of casts. They include *Turritella carlottae* Watson and *Corbula canaliculata* Hutt. The succeeding beds are not exposed, but higher up the slope loose sands are seen.

The Middle and North Dean are composed of a yellow calcareous sandstone with many comminuted shells in certain bands, and frequent inclusions of a yellow-brown sandstone, which also forms separate bands. This is probably the second Mount Brown limestone (B). The main band (D) does not here form the crest of the range, but appears in rounded hills about half a mile to the south-east. Between B and D there are sands and further yellowish-white calcareous sandstones containing "fucoids," barnacles, Polyzoa, and echinoids.

The third Mount Brown limestone (C) is a yellow calcareous sandstone, about 30 ft. thick, containing in places an abundance of *Magadina waiparensis*. It may be traced from near the South Dean to the cliffs opposite the meander in the Waipara River below the gorge, but appears to pass into a sandstone before the river is reached.

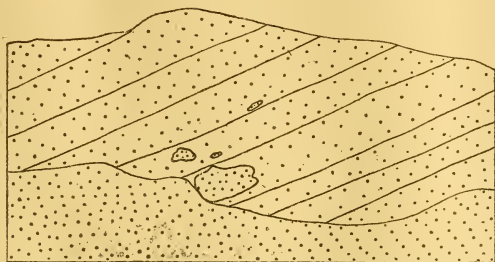


FIG. 6.—Unconformity at junction of Bobby's Creek and the Waipara River.

The Main Mount Brown limestone (D) forms the crest of the cuesta on the cliffs near the Waipara River, but higher up the hill, towards the Deans, it falls back behind the crest. It is divided into two parts by a persistent band of sand, 5 ft. thick, which contains occasional specimens of *Ostrea*, *Anomia*, and barnacles. The lower part is harder and not so rubbly as the upper, and contains few fossils but barnacles. The base of the upper part consists of a persistent shell-bed, 2 ft. thick, containing *Pecten beethami*, *P. burnetti*, *Lima colorata*, *Anomia trigonopsis*, and casts of many other species, including *Turritella*. The remainder is the usual red-brown rubbly impure limestone, containing an abundance of *Magadina browni*. The main band is bent into a syncline where it reaches the Waipara River (Plate XXI, fig. 1); the lower part consists of alternating sands and calcareous sandstone, containing *Pecten huttoni*, while the underlying sands contain *Placunanomia* sp. and *Pachymagas* not sufficiently well preserved for specific identification.

On the opposite side of the river the Main Mount Brown limestone (D) is exposed in a small syncline, truncated by the Bobby's Creek fault. It is of the usual rubbly character, and yielded *Pecten burnetti*, *Ostrea* sp., *Magadina browni*, *Rhizothyris rhizoida*, and *Pachymagas* of the *parki* series. Cup-shaped Polyzoa are fairly abundant.

Weka Creek.—In the Weka Creek the contact of the Weka Pass stone and "grey marls" is well exposed. Speight and Wild (1918) have noted that the agreement in dip is absolute, and the contact does not show any signs of unconformity, but the Weka Pass stone exhibits on its upper surface a narrow bored zone similar to that on the upper surface of the Amuri limestone. "This is succeeded by 1 ft. of slightly glauconitic sandy marl, then by 12 ft. of slightly glauconitic sandstone, passing up into sandy marl and becoming more argillaceous higher up but still preserving something of its arenaceous nature."

The thickness of the sandy mudstones is difficult to estimate, as the creek here runs obliquely to the strike, but is about 70 ft. Near the top *Amusium zitteli* is fairly common, and there are also casts of other bivalves and gasteropods, at least two species of coral, fish-scales, and Foraminifera. Such shells as exist are mostly too fragile to collect. The mudstone is succeeded by a sandstone, and then there are alternations of sandstone and mudstone up to the horizon of the second Mount Brown limestone (B).

Weka Pass.—In the middle part of the Weka Pass Stream from the road-bridge over the stream downwards, and in the railway-cuttings opposite, there are several isolated exposures of the "grey marls," but no continuous section. The lowest beds, at the bridge, are typical sandy mudstones resting directly on the Weka Pass stone. The actual junction cannot be observed, but only about 3 ft. of beds is not exposed, and each rock appears to be approaching the other in composition. From these sandy mudstones, which appear to be about 50 ft. thick, I collected casts of *Verconella*, *Crassatellites*, *Loripes*, *Nucula*, and *Nuculana*.

Lower down the stream there are two large cliffs of well-bedded soft grey sandstone, and similar beds are exposed in the railway-cuttings above. The thickness of these sandstones does not probably exceed 200 ft. They are again succeeded by a sandy mudstone of unknown thickness, exposed at the first bend of the stream above the cliff of the lower Mount Brown limestone described below: These are succeeded by loose sands, passing into a grey muddy sandstone, together about 50 ft. thick.

In the upper part of the Weka Pass Stream only the lower part of the "grey marls" is exposed, as a typical sandy mudstone near the viaduct. From this rock I collected *Limopsis aurita* Brocchi (?) and Foraminifera, and McKay's earlier collection included *Ampullina miocaenica* Suter. A selection of the Foraminifera supplied by Mr. F. Chapman was as follows: *Clavulina communis* d'Orb., *Bulimina inflata* Seguenza, *Ehrenbergina serrata* Reuss, *Nodosaria vertebralis* Reuss, *N. prismatica* Reuss, *N. consobrina* d'Orb., *N. longiscata* d'Orb., *Lingulina costata* d'Orb., *Cristellaria vortex* d'Orb., *C. gyrosalprum* Stache, *Globigerina triloba* Reuss, *Truncatulina thiara* (Stache), *Anomalina ammonoides* (Reuss), *Pulvinulina karsteni* Reuss, and *Rotalia soldanii* d'Orb. These indicate, according to Mr. Chapman, that the horizon is probably Eocene.

There are two prominent calcareous horizons in the Mount Brown beds on the south-east side of the Weka Pass, lying about 400 ft. and 800 ft. respectively above the Weka Pass stone. The upper horizon (D) forms an escarpment on the crest of the ridge, and the lower (B) presents a less prominent escarpment as a salient half-way down the slope, but in the angle between the Weka Pass Stream and the Weka Creek it forms a separate lower cuesta in front of the cuesta of the main band (D), and it assumes the same physiographic prominence between the Weka Creek and the North Dean, where, as already noted, it forms the summit of the range.

The lower horizon (B) consists, in the railway-cutting 43½ miles from Christchurch, of upper and lower hard bands, 25 ft. and 20 ft. thick, separated by about 35 ft. of sands. Both bands consist of hard brown arenaceous limestone, with sandstone intercalations, forming cavernous cliffs owing to the weathering-out of included fragments of derived sandstone. This phenomenon is well displayed in the cuesta between the Weka Creek and the Weka Pass Stream, where the derived fragments often show clear bedding oblique to that of the enclosing rock. Fossils are scarce and consist chiefly of small cup-shaped Polyzoa and barnacles, but *Anomia* sp. and partial valves of *Magadina* were observed. The lower bands are exposed on a cliff below the railway-cutting, between it and the Weka Pass Stream, where they are intersected by a small fault with downthrow to the north (Plate XXI, fig. 2). The base of the limestone on the northern (downthrown) side consists of a lenticular hard calcareous conglomerate enclosing specimens of *Cucullaea*, *Struthiolaria tuberculata* and many other gasteropods, and numerous barnacle (*Balanus*) fragments. Unfortunately the matrix is too hard to enable satisfactory specimens to be collected. The conglomerate rests upon soft grey sandstones, of which the few feet exposed show no bedding, so that the presence of an unconformity cannot be definitely asserted, but the presence of the derived fragments of sandstone in the overlying limestone makes it probable.

In the Weka Creek the lower limestone (B) flattens out just before reaching the creek-banks and is not exposed on the banks. It seems probable that it is cut off by a fault with downthrow to the south-east.

The third Mount Brown limestone (C) does not appear to be developed in the lower part of the Weka Pass or in the Weka Creek, but is again found not far below the main band (D) on the north-west face of Mount Donald, and for some distance to the south-west, where in a col in the cuesta it reaches the summit. It forms at the last point about 40 ft. of hard calcareous sandstone, in bands of 1 ft. to 3 ft. thick separated by shelly sands containing *Magadina waiparensis*, *Anomia trigonopsis*, and *Pecten burnetti*. A little nearer Mount Donald the bands coalesce to form a shelly limestone containing an exceptionally large number of derived sandstone inclusions, which weather out and give it a very cavernous appearance. It contains Polyzoa, barnacles, and shelly fragments, including *Magadina waiparensis* and *Anomia trigonopsis*. On the north-western face of Mount Donald the base contains a shell-bed with many casts of large gasteropods. It is here underlain by sands containing concretions.

The main Mount Brown limestone (D) forms, as already mentioned, the crest of the watershed south-east of the Weka Pass. It is divided by a persistent bed of sand, which outcrops just below the crest on the Weka Pass side, and yielded *Pachymagas cottoni* n. sp. and *Waipara abnormis*. This limestone crosses the railway-line in the cutting 43 miles 21 chains from Christchurch. At the northern end of the cutting there is about 35 ft. of sands exposed below the lowest bed of limestone. These sands contain occasional shells, including *Ancilla pseudaustralis*, *Pecten huttoni*, and very fragile shells of *Crepidula* sp. Immediately below the lowest limestone bed is a thin bed of broken shells, including *Anomia trigonopsis* and *Glycymeris* sp. The lowest limestone bed is 5 ft. thick. It is succeeded unconformably by 25 ft. of sands, containing many small derived pieces of sandstone, and yielding *Anomia trigonopsis*. Then follows 3 ft. of limestone, succeeded by another 25 ft. of sands. These are succeeded by the

main mass of the limestone, 25 ft. thick, containing at the top a shelly band with *Pecten huttoni*, *P. beethami*, *P. burnetti*, and *Lima colorata*. The limestone also contains many brachiopods, including species of *Rhizothyris* and *Pachymagas*, *Magadina browni*, and *Terebratulina suessi*. It is followed by 6 ft. of sands, and a further 16 ft. of nodular limestone, which contains *Bouchardia minima*, *Magadina browni*, and *Pachymagas* sp. This is followed by 3 ft. of creamy calcareous sandstone, which, as will be seen later, is best regarded as forming the base of the next horizon.

Fossils are abundant in places on the dip-slopes of the main band (D), especially near the top of the small valley entering the Weka Pass Stream between the 43 m. 21 ch. and 43 m. 3 ch. cuttings, and over the saddle at the head of this valley down to the first valley trending to the Omihi Creek. Here the uppermost rubbly band seen in the railway-cutting is well exposed near the foot of the main dip-slope, and yields a rich brachiopod fauna, besides *Pecten burnetti*, *P. beethami*, *Pecten* sp. nov., *Lima colorata*, *L. paucisulcata*, *L. lima*, *Ostrea angasi*, *O. gudezi* Suter (?), *Anomia huttoni*, *A. furcata*, *Isurus desori* (Ag.), *I. hastalis* (Ag.), small echinoids and fragments of larger species, and numerous cup-shaped and bottle-shaped Polyzoa. The brachiopods identified are *Terebratulina suessi*, *Bouchardia minima*, *Magadina browni*, *Rhizothyris scutum* n. sp., *R. rhizoida*, *R. elongata* n. sp., *R. curta* n. sp., *R. crassa* n. sp., *R. elliptica* n. sp., *R. fortis* n. sp., *R. obesa* n. sp., *R. pirum* n. sp., *R. ovata* n. sp., *R. amygdala* n. sp., *Pachymagas bartrumi* n. sp., *P. speighti* n. sp., *P. haasti* n. sp., *P. hectori* n. sp., *P. parki*, *P. McKayi* n. sp., *P. morgani* n. sp., and *P. coxi* n. sp.

The uppermost Mount Brown limestone (E) forms a prominent cuesta behind the dip-slope of the main band, and thence crosses the railway in the cutting 43 miles 2-3 chains from Christchurch, and descends into the Weka Pass Stream and Weka Creek a few yards above their junctions. The succession from the main band upwards may be followed without a break in the Weka Pass Stream and the Weka Creek, while parts of the beds are exposed on the escarpment of the cuesta to the east. The total thickness is about 100 ft., the last 35 ft. being formed by the uppermost limestone, which in the railway-cutting is a reddish-brown to yellow arenaceous limestone with numerous small pockets containing small pebbles, up to $\frac{1}{4}$ in. in diameter, of greywackes and jaspers. It contains many polyzoan and echinoid fragments.

Immediately succeeding the main limestone (D) is a creamy calcareous sandstone a few feet thick, well exposed just above the foot of the dip-slope of the main band, where it yields *Stethothyris sufflata* and *Neothyris anceps* n. sp. When followed over the first saddle into the most easterly tributary of the Omihi Stream it forms a sharp V down-stream, and on the far side is 3 ft. thick and yields *Pachymagas andrewi* n. sp. It is here followed by a hard band 2 ft. thick, in turn succeeded by more soft creamy limestone, 3 ft. thick, yielding *Lima colorata* and *Pachymagas cottoni* n. sp. This is again followed by another hard band 1 ft. 6 in. thick, and the exposed section here ends with soft calcareous sandstone containing *Lima colorata* and *Cucullaea alta* var. B. The above limestone bands are included with the uppermost limestone (E) because of the occurrence in them of *Stethothyris sufflata*.

In the gorge of the Weka Pass Stream the above calcareous sands are succeeded by blue muddy sands, about 50 ft. thick, which contain fossils sparingly throughout, and include two shell-beds. The lower 20 ft. contains *Cucullaea alta* var. B. and *Lima colorata* fairly commonly, and also yielded

Turritella concava, *Natica australis*, *Ampullina suturalis*, *Verconella costata*, *Ancilla pseudaustralis*, *Surcula fusiformis*, *Limopsis zitteli*, *Pecten williamsoni*, *P. huttoni*, *Tellina eugonia*, and *Dosinia greyi*. The lower shell-bed lies about 30 ft. below the limestone, and is exposed in the Weka Pass Stream at and below the suspension bridge, and also in the Weka Creek. It yielded *Magadina browni*, *Neothyris novara*, *Rhizothyris curiosa*, *Crepidula monoxylla*, *C. gregaria*, *C. striata*, *Polinices gibbosus*, *Galeodea sulcata*, *Sigapatella novae-zelandiae*, *Latirus brevirostris*, *Verconella costata*, *V. dilatata*, *Voluta arabica*, *Voluta* sp. cf. *protorhysa* Tate, *Ancilla novae-zelandiae*, *Dentalium solidum*, *Placunanomia incisura*, *Limopsis zitteli*, *Pecten crawfordi*, *P. burnetti*, *P. huttoni*, *Crassatellites attenziatus* (fragments), *Venericardia purpurata*, *Cytherea sulcata*, *Protocardia alata*, and *Thracia* n. sp. The upper, or *Hinnites*, shell-bed occurs at or near the base of the limestone, and is exposed in the railway-cutting, in the Weka Pass Stream and its tributary crossing the railway-line above the cutting, and in the Weka Creek. It yielded *Neothyris novara*, *Stethothyris sufflata*, *Hemithyris nigricans* mut., *Dentalium solidum*, *Pecten crawfordi*, *P. burnetti*, *Hinnites trailli*, *Lima paucisulcata*, *Ostrea angasi*, *Cytherea sulcata*, *Chione stutchburji*, *Cochlodesma angasi*, and *Protocardia alata*.

The limestone (E) closing the sequence of the Mount Brown beds contains a fair number of brachiopods and a few molluscs in the Weka Creek, the railway-cutting, and the cuesta leading to the Omihi watershed, and yielded the following species from these localities: *Crepidula gregaria*, *Galeodea senex*, *Ancilla pseudaustralis*, *Anomia trigonopsis*, *Antigona sulcata*, *Pecten burnetti*, *P. beethami*, *P. triphooki* Zitt. (?), *P. hochstetteri*, *Lima paleata*, *Terebratulina* sp. cf. *cancellata* Koch, *Stethothyris sufflata*, *Neothyris novara*, *N. iheringi* n. sp., *Rhizothyris curiosa*, *R. media* n. sp., *R. scutum* n. sp., *R. curta* n. sp., *R. elliptica* n. sp., *R. fortis* n. sp., *R. obesa* n. sp., and *Pachymagas hectori* n. sp.

As the limestone cuesta is traced from the Weka Creek past the first tributary of the Omihi Creek towards the second it exhibits no longer the characteristic brachiopods and becomes more of a hard shell-bed, the shells being mostly casts at the outcrop. It appears to be continuous past the back of Mount Donald towards the Waikare Valley, but has not been examined in this direction.

The summit of Mount Donald forms an outlier of beds resting on the main limestone band (D). These appear to be the lower beds of the *Stethothyris sufflata* zone. Park (1905) stated that some mile and a half north of the pass, near the highest part of Mount Donald, the beds were richly fossiliferous, and gave a list of forty-eight species of cetacea, fish, molluscs, brachiopods, cirripedes, and echinoids. I have been unable to rediscover this locality.

Behind the cuesta of the main limestone (D), running from the Weka Creek towards the Deans, the first cuesta is that of a shelly calcareous sandstone containing fine pebbles, which lies about 120 ft. above the main band (D). This is presumably the uppermost band (E). It has not been recognized in the Waipara end of the district.

WANGANUIAN.

Greta Beds.

The Greta, or Motunau, beds of the district are a variable series of littoral beds, consisting largely of gravels and gravelly shell-beds, oyster-beds, coarse sands, and blue calcareous or sandy mudstones, with rare lignite-seams.

The constituents of the gravels consist predominatingly of the harder elements of the pre-Notocene of the North Canterbury mountains—viz., greywackes, grits, quartzites, and jaspers; but there are also pebbles of basalts and lamprophyre-like igneous rocks. No pebbles of the underlying Notocene beds have been observed, nor has any clear unconformity with the Mount Brown beds been detected, but the faunal break is such that one may well be suspected, and it is more than probable that outside the area an overlap of these beds on to the pre-Notocene will be discovered.

Those bands with a harder cement, mostly calcareous, stand up as cuestas on the back slopes of Mount Brown, the Deans, and the hills near Glenmark, but they are not well exposed in the small creeks draining these slopes, and the best sections are those of the Kowhai River in its main branches, the Waipara River, and the Weka Creek. An intermittent section is also yielded by the railway-cuttings between Waipara and the Weka Pass.

Kowhai River and Mount Brown.—Only a part of the north branch of the Kowhai River was explored, and a discontinuous section of the Motunau beds observed in the creeks draining from Mount Brown. In a cliff facing Mount Brown, the base of which is about 200 ft. above the top of the main limestone (D), there is an oyster-conglomerate about 50 ft. thick, yielding *Ostrea arenicola*, succeeded by 50 ft. of hard calcareous conglomerate, and resting on sands with a bed of fragile shells.

In a tributary notching the cuesta of the Mount Brown beds, west of Mount Brown, lower beds are exposed. Above the main limestone (D), with *Magadina browni*, there is a gap of about 20 ft. in the succession, and then there is a further 10 ft. of brown calcareous polyzoan sandstone with much quartz, perhaps still in the Mount Brown series. This is followed by brownish-green sands and 1 ft. of calcareous sandstone. The succeeding beds are 40 ft. sands, 10 ft. fine conglomerate with pebbles of jaspers, greywackes, and dark porphyritic rocks, 50 ft. brown sands, and 10 ft. fine conglomerate oyster-beds with 8 in. boulders of a white calcareous sandstone containing friable fossils at the base, the same horizon being represented 100 yards down-stream by four separate oyster-beds separated by sands. After a gap of 50 ft. some 15 ft. of coarse conglomerate is exposed. The oyster-beds yielded *Anomia huttoni*, *Ostrea angasi*, and *O. nelsoniana*.

On the road from Onepunga to the Kowhai Valley the first beds exposed are oyster-beds and hard coarse conglomerates, lying about 200 ft. above the main Mount Brown limestone (D). In the first large cliff in the north branch of the Kowhai River below there are fine conglomerates and sands, with many oyster-beds. The next prominent bed upwards in the sequence is again an oyster-conglomerate with a hard white calcareous cement. About a quarter of a mile down-stream the first mudstone is exposed, and is a very green rock without fossils. It lies about 300 ft. above the main Mount Brown limestone (D).

The upper part of the Greta beds is exposed in the lower part of the north branch of the Kowhai River and its numerous tributaries. The rocks are fine conglomerates, gravelly shell-beds, oyster-beds, sandstones and loose sands, blue mudstones and sandy mudstones, and thin lignite-seams. Continuous exposures are not found, and, judging from neighbouring cliffs, the conglomerates and sandstones are lenticular and not persistent. Fossils are fairly abundant, but are in many cases very fragile. The oysters belong to the species *Ostrea angasi*, *O. arenicola*, and *O. corrugata*. An exhaustive collection of the other species was not made, but the following were noted: *Chione meridionalis*, *Gari lineolata*, *Modiolus australis*, *Procardia pulchella*, and *Sigapatella novae-zelandiae*.

The beds are covered unconformably by the Kowhai gravels, the junction being clearly seen in a tributary draining from Mount Brown. Mr. R. Speight informs me that a very good fossil-locality for the Greta beds has been discovered recently in the north branch of the Kowhai River.

The first cuesta behind that of the main Mount Brown limestone (D) on the Mount Brown road consists of a fine conglomerate containing sparse pebbles of quartz, greywacke, and jaspers in a white calcareous cement, and lies about 100 ft. above the main limestone. Whether this represents the uppermost Mount Brown limestone (E), or, as seems more probable, the base of the Greta series, remains uncertain. A series of alternating sands and shelly gravels capped by a hard coarse conglomerate forms the next cuesta, lying at least 100 ft. above the former. The shells represented are chiefly *Glycymeris laticostata*, *Crepidula gregaria*, and *C. monoxyla*; but I collected also *Antigona zelandica*, *Chione stutchburyi*, *Dentalium solidum*, *Dosinia greyi*, *D. subrosea*, *Ostrea nelsoniana*, *Spisula aequilateralis*, and *Verconella mandarina*.

Waipara River—For some distance below the outcrop of the main Mount Brown limestone no Notocene beds are exposed on the north bank of the Waipara River, and the base of the Greta series does not outcrop at this point. The lowest beds seen lie on the south bank, at the bend of the river opposite the end of the cuesta running down from Mount Brown (but on the opposite side of the Boby's Creek fault), and consist of sandstones with concretions, followed by mudstone, on which rests 20 ft. of fine gravelly and sandy shell-beds containing *Cerithidea bicarinata*, *Tellina deltoidalis*, *Verconella dilatata*, *Venericardia difficilis*, and other species too fragile to collect. This is followed by soft greenish mudstones yielding *Ancilla mucronata*, *Cerithidea bicarinata*, *Chione yatei*, *Cominella adpersa*, *C. quoyana*, *Crepidula gregaria*, *Mactra discors* (?), *Ostrea angasi*, *Struthiolaria papulosa*, and *Tellina deltoidalis*. Above this occur shelly conglomerates 6 ft. thick, containing *Ancilla australis*, *A. pyramidalis*, *Barnea similis*, *Sigapatella novae-zelandiae*, *Cerithidea bicarinata*, *Chione chiloensis*, *C. yatei*, *Ischnochiton maorianus*, *Cominella quoyana*, *C. adpersa*, *Crepidula costata*, *C. striata*, *C. monoxyla*, *Diplodon zelandica*, *Dosinia greyi*, *Lapparia corrugata* (?), *Lutraria solida*, *Mangilia sinclairi*, *Modiolus australis*, *Musculus impactus*, *Ostrea angasi*, *Rissoina vana*, *Seila chathamensis* var., *Verconella dilatata*, *V. mandarina*, *Terebra tristis*, *Trochus tiaratus*, *Trophon corticatus*, *Venericardia purpurata*, *Voluta arabica*, *Volutospina huttoni pseudorariospina* (?). To these about 20 ft. of mudstone succeed, containing fossils similar to the lower mudstones; then a further 10 ft. of sandy and gravelly shell-beds (mostly *Ostrea* and *Venericardia* with *Anomia huttoni*), about 25 ft. of mudstone, another *Ostrea* and *Venericardia* shell-bed, 12 ft. of muddy sands, 10 ft. of yellow sands, and 10 ft. of gravels, after which the section ends.

About a quarter of a mile down-stream on the north bank there is an exposure of mudstones with fossil wood resting on sandstones and shelly conglomerates. The mudstones yielded *Arcopecten disculus*, *Cerithidea bicarinata*, *Chione chiloensis*, *Crepidula monoxyla*, *Dosinia greyi*, *D. subrosea*, *Modiolus australis*, *Ostrea angasi*, and *Tellina deltoidalis*. These are succeeded by a muddy sandstone. After a gap in the succession further sandstones and shelly conglomerates appear.

A boulder obtained from the river-bed farther down by a settler contained *Ostrea ingens*. The matrix was a pebbly calcareous sandstone, quite similar to some of the hard bands of the Greta beds forming small cuestas on the slopes towards the Deans.

Weka Creek.—The lowest beds of the Motunau series appearing in the Weka Creek are shelly conglomerates, which are followed on the right bank by greenish mudstones, 20 ft. thick, crowded with *Chione stutchburyi*. The next beds to outcrop are a series of shell-beds yielding *Ancilla novae-zelandiae*, *Anomia huttoni*, *Barnea tiara* Tate, *Calyptraea maculata*, *C. tenuis*, *Gari lineolata*, *Glycymeris laticostata*, *Maetra dubia*, *Mytilus canaliculus*, *Ostrea tatei*, *Spisula aequilateralis*, *Trochus conicus*, and *Verconella dilatata*. Farther down-stream, in a high cliff near the road, there is a hard oyster-bed about 6 ft. thick, from which *Ostrea arenicola* was identified.

In the railway-cutting 43 miles 2-3 chains from Christchurch the uppermost Mount Brown limestone (E) is followed, apparently quite conformably, by a thin bed of white sand, showing on the south-west (creek) side of the cutting, succeeded by about 12 ft. of shelly conglomerate. This is followed by a yellow-brown polyzoan calcareous sandstone, greatly resembling the underlying limestone (E), of which 12 ft. is exposed. On the north-east side of the cutting, where the section is clearer, the shell-bed is divided in two by a mudstone intercalation, and there are loose brown sands, making a total of about 35 ft. of beds before the calcareous sandstone is reached. Park (1905) interpreted the upper calcareous sandstone as a portion of the Mount Brown beds, and considered that it was covered unconformably by the shell-beds which really underlie it. The constituents of the conglomerates are mostly coarse, hard greywackes and jaspers, but basalts and rotted lamprophyre-like igneous rocks are represented. The majority of the pebbles are 1 in. to 2 in. long, but a few up to 8 in. were observed, all well rounded. The shells collected were *Amphidesma australe*, *Ancilla novae-zelandiae*, *A. hebera*, *A. mucronata*, *Anomia huttoni*, *Cerithiella* n. sp., *Chione chilensis*, *Crepidula gregaria*, *Dentalium solidum*, *Dosinia subrosea*, *D. greyi*, *Glycymeris globosa*, *G. laticostata*, *Ostrea angasi*, *O. manubriata*, *O. tatei*, *Polinices ovatus*, *Sigapatella novae-zelandiae*, and *Spisula aequilateralis*.

Kowhai Series.

The Kowhai series consists of tilted terrestrial gravels, resting unconformably on the Greta series, and containing boulders of all the underlying Notocene beds as well as the greywackes of which they are mainly composed. The beds form the lower hills adjoining the Amberley-Waipara Plain, and have a larger development in the Moeraki Downs to the south-west of the district, and in the hills between Amberley and the lower gorge of the Waipara River. The best exposures are in the Kowhai River, but the beds are also seen in the creeks draining from the Deans and in the tributaries of the Omihi Creek.

Kowhai River.—In the high cliffs of the north branch of the Kowhai River north-east of Tobin's Road there are from 100 ft. to 200 ft. of brownish gravels dipping at a low angle to the north-east. The gravels are poorly sorted and poorly stratified, and consist mainly of greywackes, grits, and jaspers from the pre-Notocene rocks, with rare basalts. The boulders and pebbles vary from 1 ft. in diameter down to the smallest quartz grains, and there is a good deal of clay in the cement. In general shape they are angular, but the edges are always rounded. These gravels rest on a clay-bed about 18 in. thick, dipping 12° south-east, which has a sharp surface towards the gravels above, but passes down quite gradually to a series of grey gravels. These consist mostly of pebbles of the pre-Notocene, but contain also pieces of greensand, Amuri limestone, Mount Brown limestone with *Magadina browni*, and red and white sandstones.

In a tributary draining from Mount Brown unconformable contacts of these gravels with the underlying Greta beds are clearly exposed. In some cases the lowest bed of the Kowhai series rests on a surface obliquely truncating several beds of the Greta series. In other cases the surface of contact is with a single bed, but shows clear evidence of erosion in its irregular contours.

PART II.—DESCRIPTIVE PALAEONTOLOGY.

Considerable collections of fossils were made by McKay and other members of the Geological Survey, but came chiefly from the Piripauan. In 1912 and 1913 I spent several weeks in the district supplementing these collections, especially from Tertiary horizons, as a result of which I announced in 1913 that "although a classic locality for the determination of the relationships of the Cretaceous and Tertiary beds, the Middle Waipara and Weka Pass district is not well suited, owing to its poverty in molluscs, to become the standard of reference for the Tertiaries of New Zealand."

The description of the saurians by Owen, Haast, Hector, Lydekker, and Hutton has already been mentioned in the account of the exploration of the district. The Piripauan Pelecypoda were described in a palaeontological bulletin by Woods (1917), while the Gasteropoda were forwarded before the war to Professor Wilckens, of Jena, now of Bonn, and their description has been delayed. The Tertiary Mollusca were determined by Mr. H. Suter, who described the new species in 1917. The fish-remains, both Cretaceous and Tertiary, were described by Chapman in 1918. More recent collections, in 1915 and 1919, have been determined by Mr. P. G. Morgan. The Foraminifera were also forwarded to Mr. Chapman, and he is preparing a palaeontological bulletin on this group. A few of the Brachiopoda have been noticed in my earlier papers on this group, and to render this account more complete a reference to these is given below, together with descriptions of the new species. The echinoids, cirripedes, and Polyzoa have not yet been determined, but there is little good material in these groups.

TERTIARY MOLLUSCA.

An attempt has been made to use the most recent nomenclature, and many of the names employed by Suter have been rejected on account of the criticisms by Iredale, Smith, and Hedley. From a geological point of view these frequent changes in the names of common species are deplorable, but are a sign of the renewed activity in the study of the group. From a scientific standpoint there is no justification for neglecting any proposed change which bears on the face of it evidence of its correctness, and one can only hope that finality will soon be attained. In such a case as the species of the Volutidae, where the changes of generic appellation have been numerous, and authorities still differ, I have deemed it best to retain the original name *Voluta*. A few notes on individual species are appended.

Seila chathamensis Sut. var.

A specimen was obtained from the Greta beds of the Waipara River, on which Mr. Suter remarked in 1913 that it was more cylindrical than Recent examples. He added that this was the first record of this species fossil.

Anomia furcata Sut.

This finely radially costate Recent species occurs abundantly in dredge-spoils from Wellington Harbour, where it shows considerable variety of form and outline. A single specimen was obtained in 1919 from the main Mount Brown limestone (D), near the Weka Pass, and can be almost exactly matched, both as regards form and ornament, with a Recent specimen. This is the first record of this species fossil.

Anomia trigonopsis Hutt.

All the specimens recorded under this name were determined by Mr. Suter in 1913 as *A. walteri* Hector. On seeing four specimens from the White Rock River, in South Canterbury, which I collected in 1917, Mr. Suter then expressed his conviction that *Anomia walteri* was a synonym of *A. trigonopsis* Hutt., and that the latter name should be used for the Recent species.

Ostrea angasi Sow.

Concerning specimens from the oyster-beds in the tributary of the Kowhai River notching the cuesta of the Mount Brown beds west of Mount Brown, Mr. Suter remarked that the left valve is strongly ribbed, but nevertheless they are not *O. corrugata* Hutt.

Musculus impactus (Herrman).

This Recent species is *Modiolaria impacta* of the *Manual*. Mr. Suter remarked on a specimen from the Greta beds of the Waipara River that it is a much elongated form, but not *M. elongata* (Hutt.).

Mactra dubia (Hutt.).

1873. *Corbula dubia* Hutt., *Cat. Tert. Moll.*, p. 18.

1911. *Mactra chrydaea* Sut., *Trans. N.Z. Inst.*, vol. 43, p. 596.

1914. *Mactra chrydaea* Sut., *Pal. Bull. N.Z. Geol. Surv. No. 2*, p. 49.

When Suter discovered, on revising the type of Hutton's *Corbula dubia*, that it corresponded exactly with his own *Mactra chrydaea*, he rejected the earlier name on the ground that it was not figured by Hutton. This is against the International Rules, and Hutton's name must stand, unless it has been preoccupied under *Mactra*, which is, of course, quite possible.

BRACHIOPODA.

RHYNCHONELLIDAE.

Very few specimens of rhynchonellids have been obtained, and the absence of species of this family and of the Terebratulidae, although they are so common in correlative rocks in the Trelissick Basin and at Oamaru, makes the group, unfortunately, less valuable than it otherwise might be for purposes of correlation. The species represented are as follows:—

Aetheia gaulteri (Morris).

Cf. Thomson, *Geol. Mag.*, dec. 6, vol. 2, 1915, p. 389, fig. 1, a, b.

A few specimens have been obtained from the Weka Pass greensand from various localities, and are of the broad type described as *Terebratella sinuata* by Hutton.

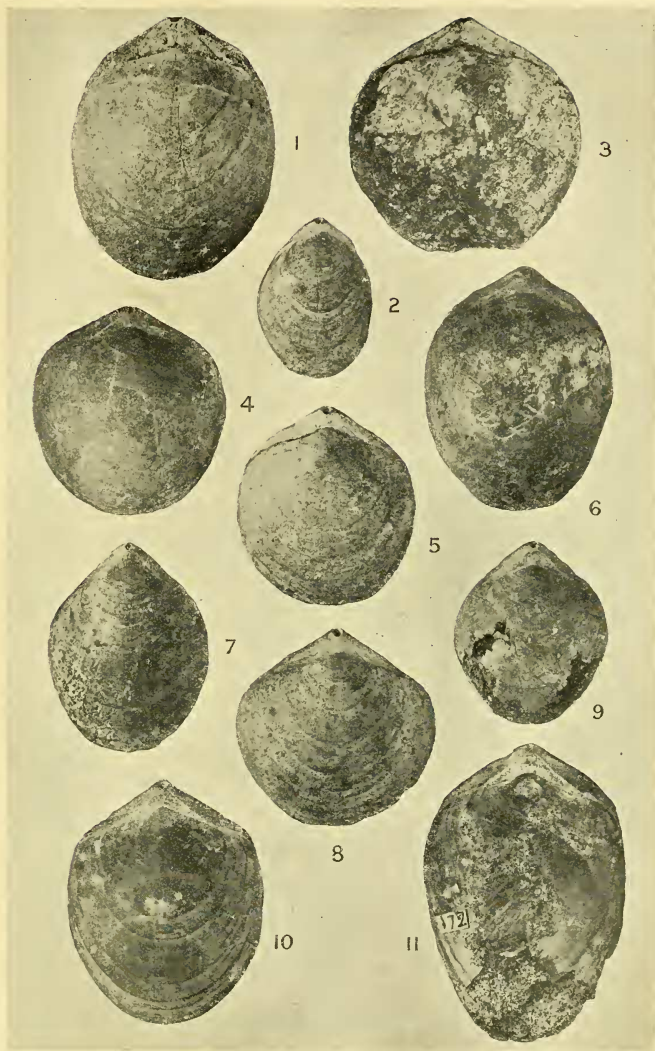
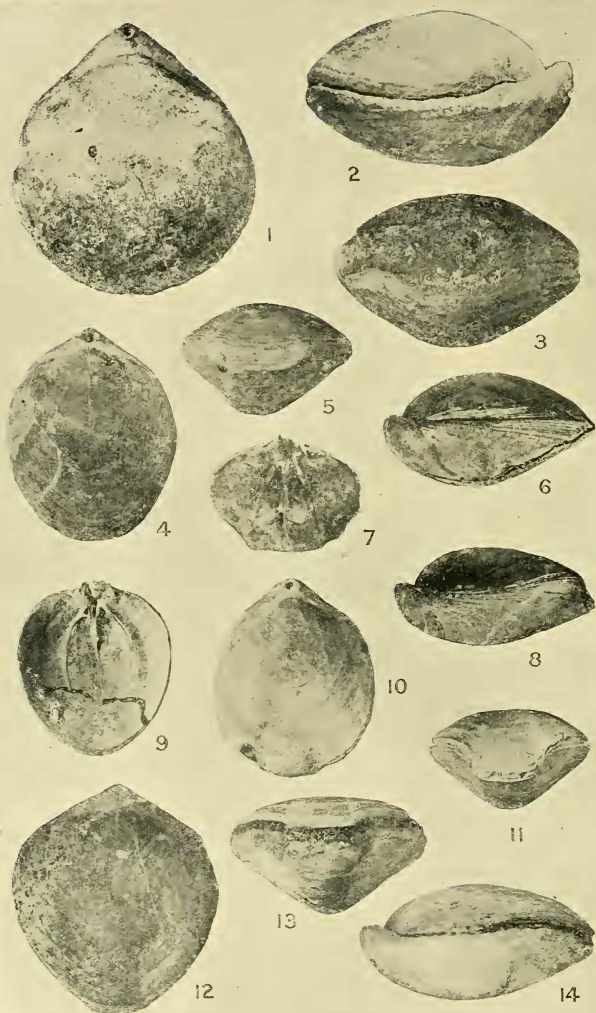


FIG. 1.—*Rhizothyris elliptica* n. sp.
 FIG. 2.—*Rhizothyris amygdala* n. sp.
 FIG. 3.—*Rhizothyris curiosa* Thomson.
 FIG. 4.—*Rhizothyris media* n. sp.
 FIG. 5.—*Rhizothyris curta* n. sp.
 FIG. 6.—*Rhizothyris rhizoila* (Hutt.).

FIG. 7.—*Rhizothyris orata* n. sp.
 FIG. 8.—*Rhizothyris lateralis* n. sp.
 FIG. 9.—*Rhizothyris pirum* n. sp.
 FIG. 10.—*Rhizothyris scutum* n. sp.
 FIG. 11.—*Rhizothyris elongata* n. sp.

(All slightly reduced.)

FIGS. 1, 2, 3.—*Neothyris iheringi* n. sp.FIGS. 4, 5, 6, 7.—*Pachymagas haasti* n. sp.FIGS. 8, 9, 10, 11.—*Pachymagas parki* (Hutt.).FIGS. 12, 13, 14.—*Pachymagas speighti* n. sp.

(All slightly reduced.)

Hemithyris nigricans (Sow.).

A mutation of this well-known Recent species is found in the uppermost Mount Brown limestone (E). It differs from Recent specimens only in its slightly smaller size and slightly more imbricated growth-lines. A similar mutation is found in Park's upper Hutchinsonian of Target Gully, Oamaru district, the lowest horizon from which any specimens referable to this species have been found.

TEREBRATULIDAE.

Terebratulina suessi (Hutt.).

Three specimens only of this species have been found, in the top of the main Mount Brown limestone (D). They agree well with the type from the Curiosity Shop.

Terebratulina sp. cf. **cancellata** Koch. (Plate XXIV, figs. 14, 15.)

A single, not very well preserved specimen from the uppermost Mount Brown limestone (E) seems referable to the Terebratulidae from its epithyrid beak characters and labiate foramen, while a fine dichotomous striation suggests *Terebratulina*. These characters are combined only in the Recent Australian species *Terebratulina cancellata* Koch, which, however, on account of its beak characters, will doubtless be made the type of a new genus. The specimen under consideration is larger than the average specimen of *T. cancellata*, but does not show the dorsal bipliation characteristic of adults of that species. Its dimensions are: Length, 38 mm.; breadth, 30 mm.; thickness, 21 mm.

No terebratulids other than the above have been obtained, and the absence of *Liothyrella* is worthy of remark.

TEREBRATELLIDAE.

Bouchardia minima Thomson.

Geol. Mag., dec. 6, vol. 5, 1918, pp. 260–61, fig. 1, a, b, c.

This species occurs locally in abundance in the main Mount Brown limestone (D).

Magadina browni Thomson.

Magadina waiparensis Thomson.

Trans. N.Z. Inst., vol. 47, 1915, pp. 399, 400, 402, 403, figs. 7, a–d, 8, a, b.

M. waiparensis has been found only in the third Mount Brown limestone (C) in the cliffs overlooking the Waipara River, and near Mount Donald. *M. browni* is extraordinarily abundant in places in the main limestone (D), and can be found in most exposures. It occurs rarely in the sandstones under the uppermost limestone (E). It is strange that *Magadina* should be so abundant in the Waipara district and be absent or very rare from the Oamaru district. There are two specimens in the Geological Survey collection from locality 308, Oamaru formation, Oamaru, Hector, 1876. One is a specimen of *M. browni*, and the other a new species of *Magadina*. The locality record gives little information, and must be accepted with caution in view of the absence of similar specimens in the extensive collections made by Uttley, Park, and myself.

Genus *Rhizothyris* Thomson.

Trans. N.Z. Inst., vol. 47, 1915, p. 399, figs. 5, *a-d*, 6, *a, b*.

Specimens of *Rhizothyris* are extremely abundant in the main Mount Brown limestone (D), and less so in the uppermost limestone (E). They present a great variety of form, the extremes being so different that it is impossible to imagine that they had not been differentiated into separate true-breeding races, although there are so many intermediates that it is obvious that the evolution either had taken place only a short time previously or was still in progress. Similar polymorphism is displayed by the specimens from Hutchinson's Quarry, Oamaru, the Maerewhenua green-sands, and the Curiosity Shop. As the forms are not exactly the same in these localities, and as a stratigraphical value may be found to attach itself to certain forms, it is desirable to create species for all the distinctive types. To show the interrelationships of these it will be necessary to describe here a few shells from the other districts. The bearing of the results on correlation is discussed in Part III of this paper.

The ancestral type from which all the species appear to have developed has not yet been found adult, but is represented by the half-grown shell of *R. curiosa* Thomson. This is shown by the growth-lines to have been a suborbicular shell with a broad, uncurved hinge-line, and without any folding. From its development in outline appears to have proceeded along three main lines.

The first series is characterized by a retention of the broad, uncurved hinge-line, but there is an increasing elongation of the shell, combined with an increasing narrowing of the front. To this series belong *R. curiosa* Thomson, *R. media* n. sp., *R. scutum* n. sp., *R. rhizoida* Hutt., and *R. elongata* n. sp.

The second series is also characterized by the retention of a broad, little-curved hinge-line, and by increasing elongation, but this is not accompanied by a tapering of the front, and the shells retain an elliptical shape. Here belong *R. curta* n. sp. and *R. elliptica* n. sp.

The third series is characterized by an increasing narrowing and curvature of the hinge-line, and elongation is accompanied by a narrowing of the front, so that the shape passes from subcircular through broadly ovate, ovate, to narrowly ovate. Here belong *R. lateralis* n. sp., *R. pirum* n. sp., *R. ovate* n. sp., and *R. amygdala* n. sp.

There has also been development in the amount of folding, and at each stage in the development in outline folding may take place preventing further development of outline in quite the same manner as would be possible to an unfolded shell. The folding is in all cases simple ventral uniplication (sulcate or concavi-convex of Buckman). In general the effect of folding on outline is to produce a sudden truncation of the front. The folded shells are also generally more convex than the unfolded. Where necessary, species have been set up for the reception of the strongly folded and convex forms—viz., *R. crassa* n. sp., *R. obesa* n. sp., and *R. fortis* n. sp.

Mr. S. S. Buckman has also pointed out to me that a further discrimination may be made according to the stage of foraminal development. All the species are permesothyrid, and almost epithyrid, but in some there has been remigration of the foramen with the production of pseudotela. I am not yet clear as to the specific value of this criterion, and have not applied it in the present analysis.

Rhizothyris curiosa Thomson. (Plate XXII, fig. 3; Plate XXIV, fig. 5.)

Trans. N.Z. Inst., vol. 47, 1915, p. 399, fig. 6, a, b.

Three specimens referable to this primitive species have been found in the uppermost limestone (E). It occurs also in the Curiosity Shop greensand, the Ngapara limestone, and the Clarendon limestone.

Rhizothyris media n. sp. (Plate XXII, fig. 4; Plate XXIV, fig. 3.)

Similar to *R. curiosa* in shape and size, but slightly more elongate. The growth-lines repeat the outline of *R. curiosa* at about three-quarters the length of the dorsal valve, and the subsequent development is in the direction of a narrowing front, making the outline shield-shaped instead of suborbicular. The sides curve outwards only very slightly from the broad, nearly straight hinge-line. The convexity, folding, and beak characters are essentially similar to those of *R. curiosa*. Length of holotype, 38.5 mm.; breadth, 35 mm.; thickness, 18 mm.

Type locality: Curiosity Shop, Rakaia River, Canterbury. Besides the type locality, this species occurs in the limestone of Fossil Point, Ashburton River (Haast coll.). One specimen from the lower shell-bed of the Weka Pass Stream and several from the uppermost Mount Brown limestone (E) are referable here.

Rhizothyris scutum n. sp. (Plate XXII, fig. 10; Plate XXIV, fig. 2.)

Shell in outline resembling a long heraldic shield. The hinge-line is nearly the breadth of the shell, and only slightly curved. The growth-lines repeat the outline of *R. scutum* at about three-quarters the length of the dorsal valve. The shell is very little folded, and both valves are rather depressed, as in *R. curiosa* and *R. scutum*. Length of holotype, 43 mm.; breadth, 34 mm.; thickness, 19.5 mm.

Type locality: Greensands, Hutchinson's Quarry, Oamaru. Besides the type locality, this species occurs also in limestone near Clifden, Waiau, Southland (G. M. Thomson coll.), in the Curiosity Shop greensands, Rakaia River, and in the main Mount Brown limestone (D) and the uppermost limestone (E) of the Weka Pass.

Rhizothyris rhizoida (Hutt.). (Plate XXII, fig. 6; Plate XXIII, fig. 7.)

1905. *Bouchardia rhizoida* Hutt., *Trans. N.Z. Inst.*, vol. 37, p. 480, pl. xlv, fig. 7.

1907. *Magellania rhizoida* Iher., *Ann. Mus. Nac. Buenos Aires*, ser. 3, tom. 7, p. 473.

1915. *Rhizothyris rhizoida* Thomson, *Trans. N.Z. Inst.*, vol. 47, pp. 397-99, fig. 5, a.

The holotype, which comes from the Weka Pass, is a shell with worn beak, which led Buckman from an examination of the figure to state that the foramen was mesothyrid, but it is really permesothyrid. Shells exactly matching the holotype in shape are not common, but the species may be allowed to include those shells intermediate in elongation between *R. scutum* and *R. elongata* which are moderately elongate, with a slightly curved hinge-line nearly the breadth of the shell, and a marked taper. These shells are moderately to strongly convex, and always show some folding.

The species is common in the main Mount Brown limestone (D), from which the holotype was doubtless derived, but does not appear to extend into the uppermost limestone. It is also common at Hutchinson's Quarry.

Rhizothyris elongata n. sp. (Plate XXII, fig. 11; Plate XXIII, fig. 11.)

1905. *Bouchardia elongata* Park, *Trans. N.Z. Inst.*, vol. 37, p. 541
(*nomen nudum*, ascribed to Hutton).

Three specimens only, of extremely elongate tapering form, have been collected—two by McKay from Hutchinson's Quarry, and one by myself from the dip-slope of the main Mount Brown limestone, Weka Pass. All three are imperfect, and I have selected the least-damaged specimen from Hutchinson's Quarry as the holotype. The hinge-line is broad and little curved, and is nearly the breadth of the shell. The sides taper gradually to a narrow front. The convexity and folding is moderate in all three specimens, and the beak little incurved.

	Dimensions in Millimetres.		
	Length.	Breadth.	Thickness.
Holotype	55	37	27
Paratype, Hutchinson's Quarry ..	34+	23.5	10
Paratype, Weka Pass ..	47	30	19+

Rhizothyris curta n. sp. (Plate XXII, fig. 5; Plate XXIV, fig. 1.)

Shell broadly elliptical, with a broad, little-curved hinge-line almost as broad as the shell; sides gently convex and regularly rounded, meeting the nearly straight front in obtuse angles. Valves moderately and nearly equally convex; anterior commissure nearly straight, with only a very slight, broad, rounded ventral sinuation. Length of holotype, 37 mm.; breadth, 33 mm.; thickness, 20 mm.

Type locality: Foot of dip-slope, main Mount Brown limestone, Weka Pass. The species occurs rarely in the type locality and in the uppermost Mount Brown limestone, and one specimen has been obtained from the concretionary bed, Deborah Cutting, Oamaru. It also occurs in a dwarfed form, up to 26 mm. long, in the Maerewhenua greensands.

Rhizothyris crassa n. sp. (Plate XXIII, figs. 8, 9.)

Shell in outline resembling *R. curta*, Valves strongly convex, anterior commissure with a broad, fairly deep, ventral sinuation. Beak erect. Length of holotype, 41 mm.; breadth, 37.5 mm.; thickness, 27 mm.

Type locality: Foot of dip-slope, main Mount Brown limestone, Weka Pass. The species is common in the type locality.

Rhizothyris elliptica n. sp. (Plate XXII, fig. 1; Plate XXIII, fig. 3.)

1915. *Rhizothyris rhizoida* (Hutt.) Thomson, *Trans. N.Z. Inst.*, vol. 47, p. 398, fig. 5, *d* (not of Hutton).

Shell elongate-elliptical, hinge-line broad and little curved, sides lightly convex and regularly rounded, front rounded. Valves moderately convex, anterior commissure with a slight rounded ventral sinuation. Length of holotype, 47 mm.; breadth, 36 mm.; thickness, 22 mm.

Type locality: Foot of dip-slope, main Mount Brown limestone, Weka Pass. The species is rare both in the type locality and in the uppermost Mount Brown limestone, and is also found in the Hutchinson's Quarry greensands. Dwarfed forms from 25 mm. to 32 mm. in length are common in the Maerewhenua greensands.

Rhizothyris fortis n. sp. (Plate XXIII, figs. 1, 2.)

Shell elongate-elliptical, hinge-line fairly broad and little curved, sides lightly convex, rounded, front narrowly truncate and nearly straight. Valves strongly convex, anterior commissure with a broad ventral sinuation. Beak nearly erect. Length of holotype, 60 mm.; breadth, 44.5 mm.; thickness, 36 mm.

Type locality: Foot of dip-slope, main Mount Brown limestone, Weka Pass. Two specimens only referable to this species have been found in the type locality, and two in the uppermost Mount Brown limestone.

Rhizothyris obesa n. sp. (Plate XXIII, figs. 6, 10.)

The outline resembles that of *R. scutum*, but the hinge-line is slightly more curved, and there is a greater approach to an elliptical shape. The valves are markedly convex, a character which differentiates the species from both *R. scutum* and *R. elliptica*, and the shell is also more folded and the beak more incurved than in these species. Apparently corresponding to the incurvature of the beak, the foramen is slightly remigrant with an indication of pseudotela. Length of holotype, 48.5 mm.; breadth, 39 mm.; thickness, 28.5 mm.

Type locality: Foot of dip-slope, main Mount Brown limestone (D), Weka Pass. A single specimen was obtained from the uppermost Mount Brown beds, in the *Neothyris* shell-bed of Weka Pass Stream.

Rhizothyris lateralis n. sp. (Plate XXII, fig. 8; Plate XXIV, fig. 4.)

Shell subcircular, hinge-line broad but slightly curved, sides convex and rounded, beak-margins nearly straight, front rounded. Valves moderately convex; there is a broad rounded sinuation in the anterior commissure. Length of holotype, 38 mm.; breadth, 37 mm.; thickness, 20 mm.

Type locality: Mount Brown beds, Weka Pass. It is uncertain whether the specimen came from the main limestone or the uppermost limestone. No examples are known from other localities.

Rhizothyris pirum n. sp. (Plate XXII, fig. 9; Plate XXIII, fig. 5.)

Shell broadly ovate or pear-shaped, with a moderately broad and curved hinge-line, sides convex and rounded, front truncated and gently rounded. Valves moderately convex, anterior sinuation slight. Length of holotype, 34 mm.; breadth, 28 mm.; thickness, 18 mm.

Type locality: Foot of dip-slope, main Mount Brown limestone, Weka Pass. There is only one other specimen referable to the species, from the escarpment of the same beds, overlooking the Weka Pass.

Rhizothyris ovata n. sp. (Plate XXII, fig. 7; Plate XXIV, fig. 6.)

Shell ovate, with a moderately broad, curved hinge-line, sides lightly convex and rounded, front truncate and gently rounded. The valves are moderately convex, anterior sinuation slight. Length of holotype, 36 mm.; breadth, 28 mm.; thickness, 18 mm.

Type locality: Foot of dip-slope, main Mount Brown limestone, Weka Pass. The species is also known from the greensands of Target Gully and Hutchinson's Quarry, Oamaru, and by a single specimen from the Maerewhenua greensands. The majority of the specimens from the latter locality belong to a similar ovate species, but with a shorter beak.

Rhizothyris amygdala n. sp. (Plate XXII, fig. 2; Plate XXIII, fig. 4.)

Shell narrowly ovate or almond-shaped, beak rather short, hinge-line short and curved, sides convex and rounded, front narrowly truncated and gently rounded. Valves moderately convex, sinuation of the anterior margin broad and shallow. Length of holotype, 29.5 mm.; breadth, 21 mm.; thickness, 14 mm.

Type locality: Greensands of Hutchinson's Quarry, Oamaru. No other specimens than the holotype are known. Two anteriorly imperfect specimens from the main Mount Brown limestone agree closely in shape, except that the beak is longer.

Genus *Pachymagas* Iher.

As in the case of *Rhizothyris*, specimens of *Pachymagas* are abundant in the main Mount Brown limestone (D), and they present an even greater variety of characters. Similar series occur in the Hutchinsonian greensands of Hutchinson's Quarry, Deborah, Kakanui, and other localities near Oamaru, while there is a different but even more varied assemblage in the Curiosity Shop greensands. The complexity of the problem, combined with the large amount of material, has delayed the completion of my memoir on the Tertiary Brachiopods of New Zealand; in the present paper I have restricted myself to the description of the majority of the species that can be recognized in the Waipara area, leaving a few till more satisfactory material can be obtained.

Among the already-described species in the Oamaruan three series may be recognized. The first includes *P. parki* (Hutt.), *P. marshalli* (Andrew), and *P. trelissickensis* Thomson, and probably also the Patagonian forms *P. tehuelcha* Iher. (the genotype) and *P. gigantea* Ortmann, and the Antarctic form *P. antarctica* Buckman. The shells are large, with a prominent mesothyrid foramen and beaks which are suberect to erect and not markedly carinate. The second series includes *P. triangularis* (Hutt.), *P. huttoni* Thomson, and the Patagonian form *P. venter* Iher. The shells are also large, with large mesothyrid foramina, with erect to incurved beaks which are carinate, and with flattened and broadly sinuated dorsal valves. The third series, perhaps generically distinct, includes *P. ellipticus* Thomson, a smaller shell with a small foramen which is submesothyrid, almost mesothyrid.* The majority of the specimens from the district belong to the *P. parki* series, while there is a fourth series represented by a new species, *P. andrewi*, with a large shell and a small foramen.

In *Neothyris*, which is a descendant of *Pachymagas*, the tendency is to increasing convexity, a restriction of the foramen, and the production and incurving of the beak with old age, so that one may conclude that in *Pachymagas* also the evolutionary process is from depressed to convex, from large to small foramen, and from suberect to erect and produced beak. Other characters which may be treated on evolutionary lines are the shape, the folding, and the cardinalia. The last, unfortunately, are rarely available in specimens from the district, owing to the hardness of the matrix.

Pachymagas parki Series.

The species may be arranged according to shape in a series from sub-orbicular to narrowly ovate, but do not all form a strictly phylogenetic series, owing to variations in the amount of folding.

* Cf. p. 380.

***Pachymagas marshalli* (Andrew). (Fig. 7.)**

1906. *Magellania marshalli* Andrew, *Trans. N.Z. Inst.*, vol. 38, p. 456, pl. iv, fig. 3, a, b.

The holotype is a poorly preserved, crushed, and somewhat distorted specimen, from which one may nevertheless conclude that it was originally a nearly suborbicular shell with short beak, broad, slightly curved hinge-line, rounded convex sides, and probably a rounded front. The convexity is slight, and the folding apparently almost negligible, but in the direction of incipient ventral uniplication. The beak is erect, little produced above the hinge-line, and possesses a moderate mesothyrid foramen with well-marked beak-ridges. Length of holotype, 49 mm.; breadth, 48 mm.

The dorsal valve was partially ground down by Dr. Andrew to expose the septum. The holotype is in the Otago Museum.

Type locality: Clarendon limestone, Milburn Quarry, Otago. No specimens are known from the Waipara district.

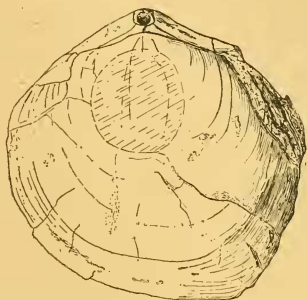


FIG. 7.—*Pachymagas marshalli*. Holotype. Natural size.

Smaller shells, up to 35 mm. in length, which agree closely in shape, occur in the Mount Somers limestone, and the greensands of Curiosity Shop, Kakanui, All Day Bay, and Three Roads.

***Pachymagas cottoni* n. sp. (Fig. 8.)**

1908. *Magellania sinuata* Thomson, *Trans. N.Z. Inst.*, vol. 40, p. 101, pl. xiv, fig. 3 (not of Hutton).

Shell broadly elliptical, with a beak of moderate length, a broad, slightly curved hinge-line, nearly straight sides, and a rounded front. Convexity

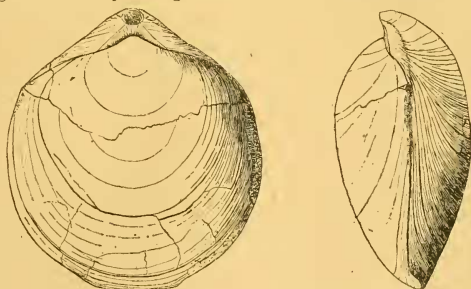


FIG. 8.—*Pachymagas cottoni*. Holotype. Natural size.

moderate, anterior commissure with a broad shallow ventral sinuation, flattened along the bottom. Beak erect, foramen moderate, mesothyrid,

attrite; the beak-ridges are sharp. Length of holotype, 48 mm.; breadth, 43 mm.; thickness, 23 mm. The species differs from *P. marshalli* only in slightly greater elongation.

Type locality: Sands below main Mount Brown limestone (D), cuesta overlooking the Weka Pass.

Smaller specimens referable to this species occur in the second creamy calcareous sandstone overlying the main Mount Brown limestone, in the Weka Pass stone at Onepunga, in the Oamaru district in the greensands of Landon Creek, Three Roads, Kakanui, All Day Bay, and Hutchinson's Quarry, and in the Caversham sandstone (A. McKay, loc. 309).

***Pachymagas bartrumi* n. sp.** (Plate XXIV, figs. 7-9.)

Shell elongate, beak fairly short, obtuse, hinge-line nearly as broad as the shell, little curved, sides very gently convex, front slightly narrowed, rounded. Valves moderately convex, ventral valve bluntly carinate longitudinally, anterior commissure with a broad, shallow, flat-bottomed ventral sinuation. Beak nearly erect, foramen large, mesothyrid, attrite. Length of holotype, 48 mm.; breadth, 38 mm.; thickness, 25 mm.

This species represents a further stage, and, so far as is known, the extreme stage, of elongation of the series *P. marshalli*, *P. cottoni*, but has an even broader hinge-line relative to the breadth of the shell.

Type locality: Foot of dip-slope, main Mount Brown limestone, Weka Pass. The species is rare in the type locality, and is not known elsewhere.

***Pachymagas speighti* n. sp.** (Plate XXV, figs. 12-14.)

Shell shield-shaped, with a rather short obtuse beak and a broad nearly straight hinge-line, whence the sides at first curve gently outwards to the middle of the shell and then taper quickly to a narrow produced front. Dorsal valve rather flat, reflected anteriorly, ventral valve moderately convex, bluntly carinate longitudinally, anterior commissure with a narrow, fairly deep, flat-bottomed sinuation. Beak nearly erect, little produced beyond the hinge-line, foramen moderately large, mesothyrid, attrite. Length of holotype, 41 mm.; breadth, 37 mm.; thickness, 21 mm.

This species, which agrees with the above three in the possession of a broad, straight hinge-line, differs from them in the narrowing of the front and the more pronounced folding. All the succeeding species possess narrower, and in general more curved, hinge-lines.

Type locality: Foot of dip-slope, main Mount Brown limestone. The species is rare in the type locality. A well-preserved cast, collected by Professor Park from the Deborah limestone, agrees closely in outline, but evidently belonged to a more convex shell.

***Pachymagas clarkei* n. sp.** (Plate XXVI, figs. 3-6.)

Shell broadly elliptical, with a short, obtuse beak, a hinge-line of moderate breadth but nearly straight, gently curving sides and a slightly produced front. Dorsal valve flattened, and sharply bent anteriorly to fit the notch in the moderately convex, bluntly carinate ventral valve, anterior commissure with a deep flat-bottomed sinuation of moderate breadth. Beak erect, little produced beyond the dorsal valve, with a large mesothyrid, attrite foramen. Cardinal process short, narrow, sharp, little more than half the height of the hinge-trough. The species is shorter and broader than *P. parki*, but otherwise resembles it in shape, convexity,

folding, and beak characters. It has, however, a much less advanced cardinal process. Length of holotype, 35 mm.; breadth, 31 mm.; thickness, 18.5 mm.

Type locality: Lower Mount Brown limestone (A), cuesta near Onepunga, where it is the commonest species.

***Pachymagas haasti* n. sp.** (Plate XXV, figs. 4-7.)

Shell elliptical, beak short, obtuse, hinge-line rather narrow, slightly curved, sides moderately convex, front slightly produced and gently rounded. Valves moderately convex, the ventral with a broad rounded longitudinal fold flattened anteriorly, anterior commissure with a moderately broad, shallow, flat-bottomed, ventral sinuation. Beak nearly erect, little produced beyond the hinge-line, foramen moderately large, mesothyrid, attrite. Cardinal process not more than one-third the length of the hinge-line, considerably less in height than the socket-ridges, rounded on the upper front surface. Length of holotype, 37.5 mm.; breadth, 30 mm.; thickness, 20 mm.

This species resembles the elliptical forms of *P. parki* in shape and elongation and in beak characters, but is less strongly folded and possesses a less advanced cardinal process. It may be regarded as ancestral to *P. parki*.

Type locality: Greensands, Deborah, near Oamaru. The species is common in most of the Hutchinsonian localities near Oamaru—viz., Devil's Bridge, All Day Bay, Three Roads—but is rare in Hutchinson's Quarry. It also occurs in the Clarendon limestone, the Ngapara limestone, and the Maerewhenua limestone. It is rare in the main Mount Brown limestone.

***Pachymagas hectori* n. sp.** (Plate XXIV, figs. 10-13.)

Shell broadly ovate, beak fairly short, hinge-line rather narrow and curved, sides regularly rounded, front slightly produced, rounded. Valves moderately convex, ventral valve with a broad rounded fold, flattened anteriorly, dorsal valve with a broad, shallow, anterior sinus, anterior commissure with a broad, shallow, flat-bottomed anterior sinuation. Beak suberect, nearly erect, not produced far beyond the hinge-line, foramen fairly large, mesothyrid, attrite. Cardinal process short, low, comparable to that of *P. haasti*. Length of holotype, 39 mm.; breadth, 33 mm.; thickness, 21.5 mm.

This species differs from *P. haasti* in the ovate outline, and from *P. parki* in the less advanced folding and cardinal process.

Type locality: Greensands of Landon Creek, near Oamaru. The species is common in most of the Hutchinsonian localities near Oamaru—e.g. Rifle Butts, Three Roads, Kakanui, All Day Bay, and Deborah—but is rare at Hutchinson's Quarry. It also occurs in the Ngapara limestone, and one specimen is known from the Maerewhenua greensands (loc. 179, A. McKay). It occurs fairly commonly in the main Mount Brown limestone, while a single specimen has been obtained from the uppermost Mount Brown limestone.

There is a further species from the main limestone which differs from *P. hectori* chiefly in being narrowly and not broadly ovate. Unfortunately none of the dozen specimens which I have collected are sufficiently well preserved to serve as a type.

Pachymagas parki (Hutt.). (Fig. 9; Plate XXV, figs. 8-11.)

1905. *Magellania parki* Hutt., *Trans. N.Z. Inst.*, vol. 37, p. 476, pl. xlv, fig. 4.

1915. *Pachymagas parki* Thomson, *Trans. N.Z. Inst.*, vol. 47, pp. 394-95, fig. 2, *b* (but not fig. 2, *a*).

The holotype (fig. 9) is a distinctly ovate form, but the majority of specimens from the type locality have a similar broad but less curved hinge-line, and the sides are less convex. The front is produced as a narrow tongue. The beak is short and obtuse. The valves are moderately convex, the ventral with a longitudinal fold which is rounded and obscurely limited posteriorly, but anteriorly is more pronounced, flattened on top and sharply limited laterally; the dorsal valve is sulcate anteriorly and sharply reflected to fit into the notch in the ventral valve; the anterior commissure shows a fairly narrow, deep, flat-bottomed sinuation. A single specimen is known in which incipient ventral biplication is shown, the anterior commissure presenting the form of a W with rounded angles. The beak is erect, not produced much beyond the hinge-line, with a moderately large, mesothyrid, attrite foramen.

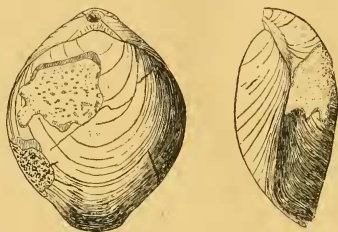


FIG. 9.—*Pachymagas parki* (Hutt.). Holotype. Natural size.

The cardinalia were described and figured by me in 1915. Attention may be drawn to the prominent cardinal process, which is about half the length of the hinge-trough, higher than the socket-ridges, and somewhat swollen in front. Length of holotype, 37 mm.; breadth, 29 mm.; thickness, 17 mm.

Type locality: Greensands, Hutchinson's Quarry, Oamaru. Restricted as above to strongly folded forms, the species is known only from the type locality (where it is common), the tuffs of Whitewater Creek, Trelissick Basin (a single specimen collected by McKay), and the main Mount Brown limestone (where it is not very common). Two closely related species have been differentiated—viz., *P. McKayi* and *P. morgani*.

*Pachymagas McKayi** n. sp. (Plate XXVII, figs. 1-3.)

Shell ovate, beak fairly long, hinge-line moderately broad, strongly curved, sides convex and regularly rounded, front somewhat produced. Valves strongly convex, especially the ventral; folding similar to *P. parki*,

* Named after the late Mr. A. McKay. The International Rules demand that, for a genitive, to the exact and complete name of a male an "i" should be added. The New Zealand Geological Survey, following Hutton, have generally adopted the permissible practice of commencing such names with a small initial letter, but this case shows the disadvantage of this procedure.

but hardly so pronounced. Beak produced well beyond the hinge-line, erect, foramen large, mesothyrid, attrite. Length of holotype, 44 mm.; breadth, 34 mm.; thickness, 25.5 mm.

This species, though somewhat less folded than *P. parki*, is more convex, and has a more prominent beak both as regards length and production dorsally of the hinge-line.

Type locality: Foot of dip-slope, main Mount Brown limestone, Weka Pass. The species is common in this limestone, and is unknown elsewhere.

Imperfect specimens, believed to belong to this species, from the main limestone between Mount Brown and the road, have a cardinal process more prominent even than that of *P. parki* and comparable to that of *Neothyris ovalis*.

***Pachymagas morgani* n. sp.** (Plate XXVII, figs. 4-6.)

Shell broadly ovate, beak moderately short, hinge-line narrow, not much curved, sides convex and rounded, tapering to a rather narrow produced front. Valves moderately convex, the dorsal with a narrow, shallow, median sulcus from about the middle, ventral with a broad rounded longitudinal fold and flattened sides, anterior commissure sloping on each side to a moderately deep, rather narrow, flat-bottomed sinuation. Beak suberect, not much produced dorsally of the ventral valve, foramen fairly large, mesothyrid, attrite. Length of holotype, 47 mm.; breadth, 41 mm.; thickness, 24 mm.

This species is less strongly folded than *P. parki*, and has a narrower hinge-line and more convex sides. It differs from *P. hectori* in its narrower and more produced front, due to narrower folding. The cardinalia are unknown.

Type locality: Foot of dip-slope, main Mount Brown limestone, Weka Pass, where it is moderately abundant. It is unknown outside the Waipara district.

***Pachymagas coxi* n. sp.** (Plate XXVI, figs. 10-12.)

Shell roundly ovate, beak of moderate length, hinge-line moderately broad and curved, sides convex and regularly rounded, front rounded. Valves moderately convex, anterior commissure with a broad, shallow, flat-bottomed sinuation. Beak suberect, hardly produced dorsally of the hinge-line, foramen large relatively to the size of the shell, mesothyrid, attrite. Interior unknown. Length of holotype, 33 mm.; breadth, 29.5 mm.; thickness, 17 mm.

This species, though smaller, agrees nearly in proportions of length and breadth with *P. morgani*, but has a more rounded front and broader folding. In these characters it agrees more nearly with *P. hectori*, but is broader, attains its greatest breadth nearer to the hinge-line, and is less convex.

Type locality: Foot of dip-slope, main Mount Brown limestone, Weka Pass. The species is fairly rare in the Mount Brown limestone, and has not been identified outside the district.

Pachymagas huttoni Series.

***Pachymagas huttoni* Thomson.** (Plate XXVI, figs. 7-9.)

Trans. N.Z. Inst., vol. 47, 1915, pp. 395, 403, fig. 2, c.

This species has already been described, but the holotype has not been figured, an omission I now rectify.

A single specimen from the Weka Pass stone at Onepunga, though only 22 mm. in length, agrees closely in all external characters with the holotype, and, moreover, possesses the same fine texture of shell and the pale purplish-brown colour which seems to be characteristic of this species. In the original description the shell was described as suborbicular, but it is slightly more elongate than this, and perhaps more correctly described as broadly ovate.

P. huttoni occurs commonly in the Waitaki limestone at Maerewhenua and Ngapara, and is also known from the greensands at the base of the Maerewhenua limestone and the greensands overlying the Wharekuri limestone.

Pachymagas andrewi Series.

Pachymagas andrewi n. sp. (Plate XXVI, figs. 1, 2.)

Shell broadly ovate, beak short, acute, hinge-line narrow, acute, sides convex and rounded, front slightly produced, rounded. Valves moderately convex, ventral valve with a broad rounded fold and slightly flattened sides, dorsal valve reflected anteriorly, anterior commissure with a broad, fairly deep ventral sinuation, not completely flattened along the bottom. Beak erect, slightly produced dorsally of the hinge-line, foramen small, mesothyrid, attrite. Cardinal process large and swollen, comparable to that of *Neothyris ovalis*. Length of holotype, 46 mm.; breadth, 44 mm.; thickness, 21 mm. (estimated). The ventral valve of the holotype is damaged, but the folding of this valve is well shown on a paratype.

This species differs from all the preceding in the smallness of the foramen. It may conceivably belong to *Neothyris* and not *Pachymagas*. It differs from *P. huttoni* in the absence of the carination of the beak. In its small foramen it agrees with *Terebratella lahillei* Ihering, a species compared by its author with *Pachymagas venter*, and perhaps a member of that series, but it is more elongate and broadly oval instead of suborbicular.

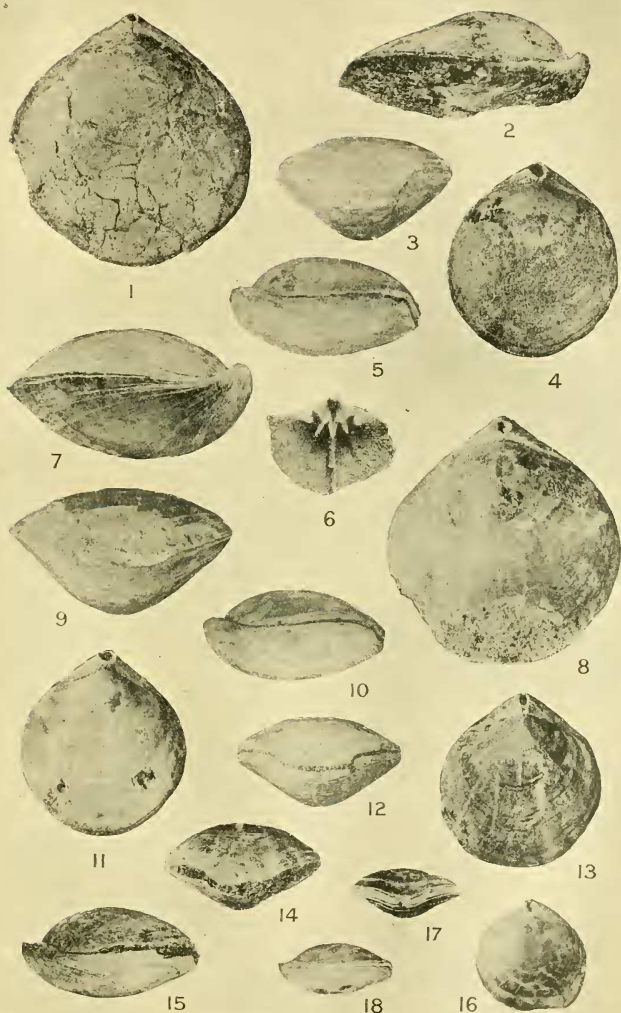
Type locality: Creamy calcareous sandstone immediately succeeding the main Mount Brown limestone, foot of dip-slope of the latter, Weka Pass. The species is rare in the type locality, and not recognized elsewhere.

Genus *Waiparia* n. gen.

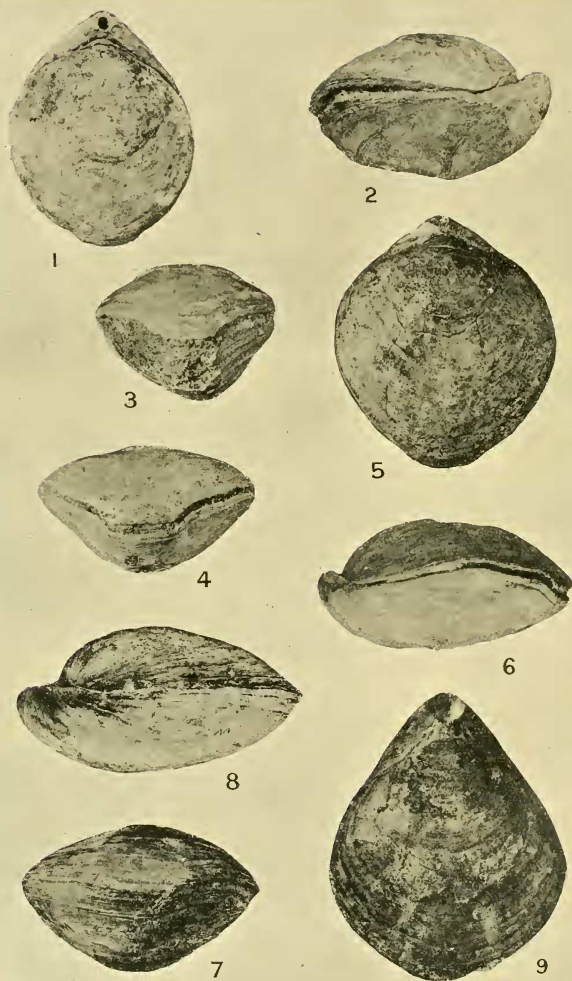
Genotype, *Pachymagas abnormis* Thomson.

A genus of the Terebratellidae with a septum showing the remains of transverse bands, and therefore presumably with a loop of the Terebratelliform pattern. Rostrum subapiculate, foramen submesothyrid, having just left the hypothyrud position, deltidial plates conjunct—i.e., united between the foramen and the dorsal umbo. In these characters the genus differs from *Pachymagas* and *Terebratella*, in which the rostrum is truncate and the foramen mesothyrid. Cardinalia similar to those of young specimens and primitive species of *Pachymagas*, with strong socket-ridges but a slender septum, a hinge-trough with flatly inclined walls and a small cardinal process confined to the umbo. The bifurcations of the septum forming the anterior walls of the hinge-trough overhang slightly outwards, and are thus more excavate than is usual in *Pachymagas*, but much less so than the hinge-plates of *Terebratella*. The teeth of the ventral valve rise from swollen bases as in *Pachymagas*.

This genus may be considered as springing from the same stock as *Pachymagas*, but lagging behind in foraminal evolution. It possibly gave rise directly to *Pachymagas* of the type of *P. ellipticus*, which possesses a foramen which is submesothyrid but almost mesothyrid.

FIGS. 1, 2.—*Pachymagas andrewi* n. sp.FIGS. 3, 4, 5, 6.—*Pachymagas clarkei* n. sp.FIGS. 7, 8, 9.—*Pachymagas huttoni* Thomson.FIGS. 10, 11, 12.—*Pachymagas coxi* n. sp.FIGS. 13, 14, 15.—*Waiparia intermedia* n. sp.FIGS. 16, 17, 18.—*Waiparia abnormis* n. sp.

(All slightly reduced.)



FIGS 1 2, 3.—*Pachymagas McKayi* n. sp. FIGS. 4, 5, 6.—*Pachymagas morgani* n. sp.
FIGS. 7, 8, 9.—*Neothyris anceps* n. sp.
(All slightly reduced)

Waiparia abnormis (Thomson). (Plate XXVI, figs. 16–18.)

1917. *Pachymagas abnormis* Thomson, *Trans. N.Z. Inst.*, vol. 49, p. 412.

This species, which I described in 1915, is characterized by its broad hinge-line and form only slightly more elongate than suborbicular.

Type locality: Sands interbedded with main Mount Brown limestone, cuesta overlooking the Weka Pass. It is also found in the top layers of the same limestone at the foot of the dip-slope, attaining here a length of 32 mm. with a breadth of 31 mm. It also occurs at Whatatutu (E. de C. Clarke coll.), and in the Awamoan mudstones of All Day Bay.

Waiparia intermedia n. sp. (Plate XXVI, figs. 13–15.)

Shell broadly ovate, beak of moderate length, acute, hinge-line moderately broad, somewhat curved, sides convex and regularly rounded, front slightly produced. Valves moderately convex, the ventral longitudinally carinate, the carina flattened anteriorly, dorsal valve anteriorly reflected and with a slight anterior sulcus. Beak erect, slightly produced dorsally of the hinge-line, foramen moderately large, submesothyrid, deltidial plates conjunct. Length of holotype, 31.5 mm.; breadth, 28.5 mm.; thickness, 16 mm.

This species is more elongate than the former, the two being about equally folded.

Type locality: Foot of dip-slope, main Mount Brown limestone, Weka Pass. The species is fairly common in this locality, some of the shells being rather more convex and more strongly folded than the holotype. It also occurs in flattened specimens in the Awamoan mudstones of All Day Bay, the Waikouaiti sandstone, and the Wharekuri greensand (McKay). There are forms still more elongate found in the greensand and mudstones of All Day Bay, and in mudstones at the junction of the Brown River with the Aorere River, Nelson. For these a further species must be set up.

Genus **Neothyris** Douvillé.

Neothyris campbellica (Filhol).

1885. *Waldheimia campbellica* Filhol, *Mission de l'île Campbell*, pp. 173–74, fig. 7, Nos. 1, 2.

This species was distinguished by its author from *N. lenticularis* on account of its narrower shell and more detached beak. The shell is oval with a strongly curved hinge-line, the beak passing into the sides without an angle. The beak is considerably produced dorsally of the hinge-line, but is erect and not incurved towards the dorsal valve.

As thus defined from topotypes, the species is common in the Wanganui. There is one specimen from the uppermost Mount Brown limestone which must be referred here.

Neothyris ovalis (Hutt.).

1873. *Waldheimia lenticularis* Hutt., *Cat. Tert. Moll. Ech.*, p. 35 (not of Deshayes).

1886. *Waldheimia ovalis* Hutt., *Trans. N.Z. Inst.*, vol. 18, p. 335.

1905. *Magellania lenticularis ovalis* Hutt., *Trans. N.Z. Inst.*, vol. 37, p. 475, pl. xlv, fig. 2.

1915. *Neothyris ovalis* Thomson, *Trans. N.Z. Inst.*, vol. 47, p. 395, fig. 2, d, e.

This species was distinguished by its author from *N. lenticularis* for much the same reason as in the case of *N. campbellica*—viz., the narrower shell—but it may be distinguished from the latter by its broader and less curved hinge-line, the sides making an obtuse angle with the beak. The beak is less produced dorsally of the hinge-line and is erect, with a foramen rather larger than that of *N. campbellica* and *N. lenticularis*.

As thus defined the species is common in the Wanganuian, and there are several specimens from the uppermost Mount Brown limestone which may be referred here.

Neothyris novara Iher.

1864. *Waldheimia lenticularis* Suess, *Reise der "Novara,"* Geol. Th., bd. 1, abth. 2, p. 56, taf. x, figs. 3a, 4a, 4b (not of Deshayes).
 1903. *Magellania novara* Iher., *Ann. Mus. Nac. Buenos Aires*, ser. 3a, t. 2, p. 326.
 1905. *Magellania novara* Hutton, *Trans. N.Z. Inst.*, vol. 37, p. 475, pl. xlv, fig. 3.
 1907. *Magellania Ameghinoi* Iher., *Ann. Mus. Nac. Buenos Aires*, ser. 3a, t. 7, p. 472 (not of Ihering, 1903).

As Ihering appears to have had before him at the time of naming this only the description and figures of Suess, the specimens treated by Suess must be regarded as the syntypes. - Of these I select the specimen from Motupipi (fig. 4a, 4b) as the lectotype. This agrees with Hutton's interpretation of the species. Ihering in 1907 united the species with his *Magellania Ameghinoi*, but since the thickness of the latter is stated never to exceed half the length, whereas in *N. novara* it is always more than half, the two may be easily distinguished.

The species is broadly oval like *N. lenticularis*, but has a much straighter hinge-line. In the lectotype, and in a few specimens from the Weka Pass, the sides make no angle with the beak; but in the majority of the specimens from the Weka Pass, and also in others from the Takaka limestone, the sides are less convex and make an obtuse angle with the beak. The species is common in the uppermost Mount Brown limestone.

Neothyris iheringi n. sp. (Plate XXV, figs. 1-3.)

Shell broadly oval, beak fairly long, acute, hinge-line long and sharply curved, sides convex, meeting the beak and the rounded front without an angle. Shell moderately convex, folding slight. Beak considerably produced dorsally of the hinge-line, erect and well detached from the hinge-line, foramen small, mesothyrid, attrite. Length of holotype, 49.5 mm.; breadth, 44 mm.; thickness, 28.5 mm.

This species differs from *N. novara* and agrees with *N. lenticularis* in the strong curvature of the hinge-line. It is distinguished by the detachment of the beak from the latter, in which the beak is incurved towards the dorsal valve.

Type locality: Uppermost Mount Brown limestone (E), Weka Pass. The species is fairly abundant in this locality, and is unknown elsewhere.

Neothyris anceps n. sp. (Plate XXVII, figs. 7-9.)

Shell ovate, beak large, obtuse, hinge-line rather narrow, strongly curved, sides convex and rounded, greatest breadth anterior to the middle, front

slightly produced. Valves moderately and regularly convex, folding very slight. Beak suberect, not produced dorsally of the hinge-line, foramen very large, mesothyrid, attrite, deltidial plates striate parallel to the hinge-line. The septum shows no sign of transverse bands, so that the loop is presumably Magellaniform. The cardinal process is of a primitive type, confined to the posterior part of the hinge-trough. Length of holotype, 53 mm.; breadth, 42 mm.; thickness, 27 mm.

The species is easily distinguished from other *Neothyris* by the size of the foramen.

Type locality: Creamy calcareous sandstone immediately following the main Mount Brown limestone, Weka Pass, where it is common.

Genus *Stethothyris* Thomson.

Stethothyris sufflata (Tate).

1880. *Waldheimia* (?) *sufflata* Tate, *Trans. Roy. Soc. S. Austral.*, vol. 3, pp. 157–58, pl. vii, fig. 3; pl. viii, fig. 4.

1885. *Magellania sufflata* Hutt., *Quart. Journ. Geol. Soc.*, vol. 41, p. 558.

1889. *Magellania sufflata* Tate, *Trans. Roy. Soc. S. Austral.*, vol. 23, p. 253.

1905. *Magellania sufflata* Hutt., *Trans. N.Z. Inst.*, vol. 37, pp. 476–77.

Specimens from the uppermost Mount Brown limestone (E), though showing considerable variation, agree closely enough externally with the Australian species in shape, convexity, and folding, and in the incurvature of the beak. In the last character senile individuals often show a beak touching the dorsal valve, so that the pedicle must have atrophied.* The cardinalia are characterized especially by the flattening of the ventral surface of the socket-ridges anteriorly, the production of the crural bases into the hinge-trough (seen in young specimens), and the swollen nature anteriorly of the cardinal process, which, though large, is not very high.

The characters of the beak and cardinal process suggest derivation from a stock of considerable antiquity, and forbid its ascription to *Neothyris*, which only appeared at this stage and did not attain similar characters until a much later period in *Neothyris lenticularis*. The characters of the cardinalia are not inconsistent with derivation from those of *Stethothyris utleyi*, and the shell shows the early sulcation of the dorsal valve exhibited by *S. pectoralis*, so that the species seems best placed in *Stethothyris*.

The species is common from the creamy calcareous sandstone following the main Mount Brown limestone at the Weka Pass to the top of the uppermost limestone, and is unknown elsewhere in New Zealand.

PART III.—CORRELATIONS AND THE CLASSIFICATION OF THE NOTOCENE.

CLARENTIAN.

No beds belonging to this division of the Notocene have been found in the district, nor in the North Canterbury area. In this it differs from east Marlborough, where the Amuri limestone is underlain by a great thickness of Clarentian beds (*cf.* Thomson, 1919A).

* *Cf.* BUCKMAN, *Pal. Ind.*, n.s., vol. 3, mem. 2, p. 17, 1917.

PIRIPAUAN.

The complete fauna recorded from the *Ostrea* beds is as follows: *Nemodon* (?) sp., "*Arca*" *hectori* Woods, *Cucullaea* sp., *Trigonia hanetiana* d'Orb, *Ostrea* sp. cf. *dichotoma* Bayle, *Pecten* (*Camptonectes*) *hectori* Woods, *Cardium* sp., *Pugnellus waiparensis* Trechmann, and a rhynchonellid. Of these, *Trigonia hanetiana* and *Pecten hectori* are found also in the calcareous conglomerate and black grit respectively of Amuri Bluff and in the *Ostrea* bed of the Malvern Hills, and *Ostrea* sp. cf. *dichotoma* occurs also in the *Ostrea* bed of the Malvern Hills. Woods considers that the *Trigonia* and *Pecten* indicate that the *Ostrea* bed belongs to the horizon of the Amuri series of Amuri Bluff, and is equivalent to the *Ostrea* bed of the Malvern Hills.

The *Ostrea* bed of the Trelissick Basin contains *Ostrea* sp. and *Inoceramus* sp., which have not yet been obtained in specifically determinable specimens, and also a small rhynchonellid, as yet undescribed, which is specifically identical with one found in the *Ostrea* bed of the Malvern Hills. It may, therefore, be also correlated with the *Ostrea* bed of the Waipara.

Ostrea beds of similar stratigraphical position and presumably of the same age are known from the upper Motunau River (McKay, 1881), from the Mount Cass Range,* and from the Harper River (Speight, 1917B). There must be other correlative beds in the area between Motunau and Amuri Bluff, but they have not been described in such a way that they can be identified and correlated.

Woods (1917) states that the fossils of the Amuri group of Amuri Bluff include only a few forms identical with species found in other parts of the world, but these and the affinities of the other species show that the fauna is of the Indo-Pacific type, and is of Upper Senonian age. Of the Waipara species, *Trigonia hanetiana* is one of the characteristic species of the Quiriquina beds of Chile, while the *Ostrea* is similar to a species found in the Senonian of other regions.

The complete saurian fauna from the "saurian beds" and Waipara greensands of the Waipara is as follows: *Platecarpus oweni* (Hector), *Cimoliosaurus australis* (Owen), *C. hoodi* (Owen), *C. holmesi* (Hector), *C. haasti* (Hector), *C. caudalis* Hutt., and *Leiodon haumuriensis* Hector. The "saurian beds" of Amuri Bluff contain an almost identical assemblage, concerning which Dr. C. W. Andrews has stated, according to Woods (1917), that it indicates an horizon near the top of the Cretaceous, and that it is very similar to the reptilian fauna of the Niobrara chalk of the United States, which is of Senonian age.

The fish-remains from the "saurian beds" comprise *Scapanorhynchus subulatus* (Ag.), a species ranging from Albian to Danian; *Odontaspis incurva* (Davis), found also in the Tertiary of New Zealand and Australia; and vertebrae of *Lamna* (?).

The Mollusca of the "saurian beds" include *Malletia* (*Neilo*) *cymbula*, which resembles *M. pencana* (Philippi) from the Quiriquina beds; *Trigonia waiparensis* Woods, comparable in ornament with *T. parva* Brüggen from the Senonian of north Peru, and with *T. crenifera* Stoliczka from the Ariyalur group, of southern India; and *Thracia* sp. None of these species has been found at Amuri Bluff or the Malvern Hills. The gasteropods from the Waipara have not yet been described.

The "saurian beds" and Waipara greensands are without doubt correlative with the similar beds of Amuri Bluff. Saurians are also known from the

* R. SPEIGHT, personal communication.

neighbourhood of Greenhills, Gore Bay, the Jed River, and the upper Motunau, and a single bone has been obtained from the Malvern Hills in the concretionary beds above the Selwyn Rapids beds.

All the above beds which are correlatives of the Piripauan of the Waipara occur in the area between the Rakaia River and Kaikoura Peninsula, and in all these localities, except in the Malvern Hills, the Amuri limestone is found above the Piripauan. The only other beds of the same age in the South Island are those of Shag Point, doubtfully referred here. The fossils are poorly preserved, but they appear to include a *Trigonia* allied to *T. pseudocundata* Hector and *Pugnellus marshalli* Trechmann.

In the North Island, Piripauan beds may occur in the east coast of Wellington Province and in the Gisborne district, but further exploration is wanted in these regions. In the North Auckland district there is a limestone somewhat similar to the Amuri limestone—viz., the hydraulic limestone—and it is underlain in the Kaipara district by mudstones, greensands, and brown sandstones, yielding ammonites and other molluscs, and a saurian bone. Marshall (1917B) described two species of ammonites as *Kossmaticeras* with Senonian affinities, a third as *Lytoceras* sp. with Utatū affinities, an Oamaruan mollusc (*Panope worthingtoni* Hutt.) identified by Suter, and a cast of *Phacoides* (*Here*) sp., a genus which did not live before the Eocene according to Cossman; and, moreover, he considered that the beds containing this fauna rest upon a Miocene limestone. Comment seems almost unnecessary. Woods has made it clear that the Clarentian and Piripauan faunas of Marlborough and Canterbury are typical Cretaceous faunas without any intermixture of Tertiary species. The probabilities seem to be that Piripauan beds are present in the Kaipara district, and that the Oamaruan Gibraltar limestone is faulted down, and does not really underlie the Piripauan. *Panope worthingtoni* Hutton is one of the species of which the type was missing when Suter redefined the Tertiary Mollusca, but Marshall's figure agrees very closely with Woods's figure of *Panope clausa* Wilekens from Amuri Bluff. The affinities of the specimens classed as *Lytoceras* sp. and *Phacoides* (*Here*) sp. may be neglected until better specimens are available, since neither retained the external ornament.

The hydraulic limestone also occurs in the Whangarei district, and Piripauan beds are also to be expected here, but no distinctive fossils have yet been found.

KAITANGATAN-AMURI LIMESTONE.

The reasons for which I have correlated the Amuri limestone with the Kaitangatan are that the Wangaloa beds of the Kaitangatan contain a fauna intermediate between those of the Piripauan and the Oamaruan, while the Amuri limestone occupies a stratigraphical position between Piripauan and Oamaruan. No common species have yet been described. Trechmann (1917) considers, on the evidence of the Mollusca, that the Wangaloa beds "should apparently be of Maestrichtian age." Chapman, on the evidence of the fish-remains and Foraminifera, considers the Amuri limestone of Danian age.

In 1916 I stated my conviction that the Amuri limestone is in itself a Cretaceous-Tertiary rock, Cretaceous at the base and Tertiary at the top, the reason for the latter statement being the occurrence in the Amuri limestone of the Trelissick Basin of an Oamaruan fauna in a tuff band 10 ft. from the top of the limestone. The rock I termed the Amuri limestone in the Trelissick Basin has the same stratigraphical position—i.e., it lies above rocks with a Senonian fauna, and underlies rocks with an Oamaruan fauna—

and, although it is usually more marly than the Amuri limestone of the coastal district, it is in places quite indistinguishable lithologically from it. Speight (1917A) has accepted this correlation. Now, however, from an examination of Foraminifera from two localities, Mr. Chapman considers that it is "probably Eocene." If this view is confirmed, it certainly demands an unconformity between this rock and the underlying Piripauan beds—an unconformity of which Speight was unable to find any trace. Nevertheless, in view of Chapman's correlation, it is unsafe to take into account the molluscan fauna referred to above in attempting to correlate the Amuri limestone of the Waipara or Amuri Bluff.

Chapman's identifications of the Foraminifera make it quite clear, however, that Marshall's correlation of the Amuri limestone with the Ototara limestone is mistaken. On the basis of the Foraminifera Chapman declares the Amuri limestone Danian, and the Weka Pass stone and "grey marls" Eocene. On the same basis Marshall declares the Ototara limestone Miocene. The correlative of the Ototara limestone in the Waipara section must, then, lie above the "grey marls," and this accords well enough with the evidence, to be discussed later, from the molluscs and brachiopods.

Outside the area north of the Rakaia River there is no limestone in the South Island that can be correlated with the Amuri limestone. It appears, however, to be present in east Wellington, and to be represented in North Auckland by the hydraulic limestone of the Kaipara and Whangarei districts. Marshall (1919) has remarked that I have objected to this correlation; but what I objected to in 1917 was his correlation of the Whangarei polyzoan limestone with the Amuri limestone by first correlating the Whangarei polyzoan and hydraulic limestone. I merely pointed out—and it is still true—that no palaeontological or stratigraphical evidence has been presented for the correlation of the Amuri limestone and the hydraulic limestone of the Whangarei district. Marshall the same year supplied the evidence so far as the hydraulic limestone of the Kaipara was concerned, and there is no reason to doubt that the hydraulic limestone of the two regions is the same. I do not agree, however, that the Whangarei polyzoan limestone is of the same age or older, any more than is the limestone of Gibraltar Rocks, in the Kaipara district. I have observed Oamaruan mollusca below the polyzoan limestone of Horahora, and have little doubt that both it and the Gibraltar Rocks limestone are Oamaruan. The geological survey of this district, however, which is at present in progress, will doubtless settle this point.

OAMARUAN.

The age of the Oamaruan has been commonly accepted as Miocene for some years, very largely on account of Chapman's determination of the Foraminifera of Waikouaiti Head, and his demonstration of the Miocene age of the older Tertiaries of Australia. Having never been willing to admit that the contact of the Amuri limestone and the Weka Pass stone, though doubtless a disconformity, could bridge the gap between Cretaceous and Miocene, I formed the opinion either that the Amuri limestone must include the Eocene or that the Oamaruan ranged down from Miocene to Eocene; and a large part of my explorations for several years past have been directed to obtaining direct evidence of the age of the Amuri limestone, and to ascertaining the fauna of the lower members of the Oamaruan. In 1915 I endeavoured to show that the beds at Waikouaiti from which the Foraminifera described by Chapman as Miocene were obtained were upper Oamaruan. There can be no doubt from the lists of fossils I have quoted

earlier in this paper that the Weka Pass stone and "grey marls," as well as the Mount Brown beds, are Oamaruan; and, as Chapman refers the Weka Pass stone and "grey marls" to the Eocene, it follows that the Oamaruan ranges from Eocene to Miocene. The contact between the Amuri limestone and Weka Pass stone is a disconformity, but bridges only the gap between Danian and Eocene.

Former geologists, notably Hutton and Park, have correlated the Weka Pass stone with the Ototara limestone, believing the lower Oamaruan beds to be missing. Marshall, on the other hand, has correlated it with the Hutchinsonian. The evidence of the Foraminifera suggests that it correlates rather with the Ngaparan and Waiarekan. The evidence of the molluscs is indecisive; that of the brachiopods, on the other hand, is practical proof that the main Mount Brown limestone (D) is Hutchinsonian and the uppermost Mount Brown limestone (E) Awamoan, leaving all the 800 ft. of lower beds, down to the Weka Pass greensand, for the Ototaran and Waiarekan.

Some remarks on the relative value of the Mollusca and Brachiopoda in correlation seem desirable in view of the recently expressed opinion of Marshall (1919) that the latter are far less satisfactory for purposes of correlation, the reasons being that they occur sporadically and in a small number of species as compared with the Mollusca, and that the species are hard to identify with certainty. The first is a valid objection, and is well illustrated in the Mount Brown beds, which are rich in Brachiopoda and yet have yielded only four specimens of *Terebratulina* and none of *Liothyrella*, genera which are abundant in the Trelissick Basin and at Oamaru. Nevertheless, the Brachiopoda are sufficiently widespread to enable their range to be established with a considerable degree of certainty, and it is illogical to neglect them if they are present in any rock and can be used. The small number of species is an advantage in one respect: it enables a single man to know the whole fauna intimately, and to apply to the whole of it every known method of study. This is not the case with the molluscan fauna, of six hundred or eight hundred species; and we can never expect entirely satisfactory results until we have students confining themselves to a few families, and studying these not from the point of view of New Zealand Tertiary species alone, but making themselves familiar with all the species, both living and fossil, in all parts of the world.

One marked difference between the Oamaruan brachiopod and molluscan faunas is that the former is practically an extinct fauna, not surviving the Oamaruan, except for a very small percentage, whereas the latter shows a very much greater percentage of living species. The brachiopods, therefore, would be expected to be of the greater value in correlation.

The chief disadvantages of the Tertiary molluscan fauna are the great range of the majority of the species and the different facies of the fauna according to station, which makes it a matter of great difficulty to ascertain accurately the range of any given species. Until this is known it is, of course, obvious that the occurrence of a species in a list gives little help. Marshall (1919) has given a list of characteristic species from his different series, but many of these species range widely in higher or lower series. Thus, of the Nukumarū series, Suter has determined *Melina zelandica* from the Waiarekan of the Oamaru district, and Marshall himself has recorded *Struthiolaria frazeri* from the Wangaloa beds. Of the Waipipi series, *Cardium spatiosum* is known from the Awamoan of Oamaru and the Trelissick Basin. Of the Target Gully series, *Venericardia pseutes* and *Terebra orycta* range from Waiarekan to Awamoan, while *Chama huttoni* occurs in the

Wanganui of Castle Point. Of the Ototara series, *Ostrea nelsoniana* ranges from Waiarekan to Waitotaran, and *Lima laevigata* from Waiarekan to Hutchinsonian. Of the Wharekuri series, *Exilia dalli* has one record from the Waiarekan and three from the Awamoan, while *Polinices huttoni* has three from the Waiarekan and seven from the Awamoan. The above ranges are from my analysis of the Oamaruan fauna of Oamaru and South Canterbury described below.

In reply to the charge of neglecting the large amount of palaeontological knowledge we already have, I can but point to the above statements, which show that it is very dangerous to generalize on our existing knowledge, and which justify my caution. It seems to me that two lines of advance are open. One is the more detailed study of the species on evolutionary lines (such as I have been attempting in the brachiopods and limpets) with a view to defining valid species of limited range, and to arranging the species in an evolutionary order. Cossman's and Murdoch's criticisms of Suter's identifications illustrate the possibilities, but the best results can be expected only from an evolutionary study. The other is a careful and detailed analysis of the available lists with a view to discovering the range of the species as at present defined.

The procedure which promises the best results depends on the delimitation in New Zealand of stratigraphical or diastrophic provinces within the bounds of each of which the various rocks of given age are stratigraphically similar and can be correlated without further demur. One such district, in which none but Oamaruan marine rocks are developed, ranges from Oamaru to Mount Somers. The sequence is everywhere—coal-beds, sands, greensands, limestones, mudstones, and sands—except for some differences at Oamaru and Mount Somers due to the development of volcanic rocks.

Marshall has stated that endless confusion would be caused by attempts to place the various beds near Oamaru in the stages as defined by me. If this is the case in a district so simple as Oamaru, a district "undisturbed by any minor stratigraphic movements," and one on which Marshall is prepared to base the whole classification of the Notocene, then we may as well give up all detailed stratigraphy in New Zealand. Neither Park nor Uttley has encountered this endless confusion, but both have greatly increased our knowledge of the district by attempts to place the beds in the various stages. While it is not denied that there are difficulties, these are difficulties that exist in the nature of things, and not because of the adoption of certain stages, although the use of the latter has called attention to them, and will probably hasten their solution.

Taking the limestones as Ototaran (*pace* Park), we have the underlying rocks Waiarekan* and the overlying rocks Awamoan, the Hutchinsonian being mostly difficult of recognition, and perhaps included in the upper of the two limestones that are usually to be distinguished outside Oamaru. Within this province there are numerous localities from which lists of fossils have been published, and in addition Mr. Suter determined all the old Geological Survey collections and also further collections made by me. These lists are as yet unpublished, but the Director of the Geological Survey has kindly given me access to them. I have divided the province into the geographical districts of Oamaru, Waitaki Valley, Waihao, Pareora, and Kakahu, and have plotted each occurrence in such a way that for each stage I have retained a record of how many districts and how many localities

* I have not taken into account Park's Bortonian, because in the type locality for this stage the fossils are practically all casts.

within each district a given species has been collected from. Part of this analysis, applying to the species from the Waipara – Weka Pass district, is given below in Table V.

One immediate advantage of such a list is that it shows clearly which species are based on single or few records, suggesting, in such cases as that, for example, where a Recent species is recorded from the Waiarekan and no higher stage, that the specimens are in need of critical re-examination before this evidence for the range of the species can be fully admitted.

A striking feature of the lists is the number of species which range throughout the Oamaruan, and the comparatively few, except in the case of the Awamoan, which are confined to a single stage. The reason for the latter is that the majority of the good fossil-localities are Awamoan—viz., Awamoa, Target Gully, Ardgowan, Otiake, Pukeuri, Mount Harris, Blue-cliffs, Pareora River, White Rock River, Holme Station, Sutherland's, and Kakahu River. The only large lists from the Waiarekan are from Black Point (where the fossils are nearly all casts), Wharekuri, Waihao greensands, and Kakahu coal-beds. I directed most of my collecting to Waiarekan localities, in order to redress the balance; but the results are still scanty compared with the Awamoan, and as a result the use of the analysis for comparison of fresh lists will tend to favour correlation with the Awamoan, as will be seen below.

The percentages of Recent species in the total faunas of the province may be estimated in two ways—viz., by actual records, or by implication: *i.e.*, if a species in the Waiarekan is also known from the Awamoan or Recent it may be credited to the intermediate rocks. The numbers of species and percentages of Recent species are as follows: By actual records—Waiarekan, 221 (Recent, 56 = 25 per cent.); Ototaran, 90 (Recent, 28 = 31 per cent.); Hutchinsonian, 97 (Recent, 36 = 37 per cent.); Awamoan, 336 (Recent, 113 = 34 per cent.): by implication—Ototaran, 178 (Recent, 69 = 39 per cent.); Hutchinsonian, 207 (Recent, 82 = 40 per cent.); Awamoan, 347 (Recent, 137 = 39 per cent.). It is to be expected that when the collections from the lower stages are as exhaustive as those from the Awamoan the percentages obtained by the two methods will approach one another more nearly, and also that there will be a regular increase from the Waiarekan to the Awamoan. It would be premature to assume that there had been a sudden introduction of new forms in the Awamoan, although that is the actual suggestion of the lists.

To ascertain the evidence presented by a fresh list from any locality, the best method appears to be to calculate the percentages of records in each stage of the species in the new list. A somewhat similar method was used by Marshall in 1919. If the analysed list is extended to include the stages older and younger than the Oamaruan, then for any given fresh list a series of percentages for each stage may be calculated which will rise to a maximum for the stage to which the list belongs. The nearer this maximum approaches 100 per cent. the higher the probability will become that the correlation is correct. The percentage of Recent species will fall into its place as only one of a series of percentages. At present, however, owing to the fact that the faunas of the various stages are so incompletely known, and that the fuller knowledge of the Awamoan fauna gives proportionately higher percentages for that stage, greater weight than will later be necessary must be attached meanwhile to the percentage of Recent species.

Applying the above method to the Wangaloa and Hampden faunas, we get the following percentages (using the method of implication):—

			Wangaloa Beds.	Hampden Beds.
Precinctive species	..	..	.. 51	42
Waiarekan	..	..	.. 39	39
Ototaran	..	..	.. 35	32
Hutchinsonian	..	..	.. 35	30
Awamoan	..	..	.. 35	32
Recent species	..	..	.. 8	9

The percentage of precinctive species in each of these faunas exceeds that of those ranging upwards into the Waiarekan or higher beds, and justifies Marshall's conclusion that they are both older than Oamaruan, a point upon which I had previously expressed doubt so far as the Hampden beds were concerned. The table also favours the correlation of the two faunas, although it should be noted that only six species are common to both, and these six species are all also Waiarekan.* We may therefore add the Wangaloa and Hampden lists as a fresh column to the analysed Oamaruan lists.

For stages later than the Oamaruan good lists are not available, and we must await Murdoch and Marshall's account of the Wanganui beds. For the purposes of this paper I have used the lists given by Hutton (1886) for Wanganui and Petane, supplementing them by unpublished determinations by the late Mr. H. Suter. These give a total of 219 species from Wanganui, with 80 per cent. Recent, and of 194 from Petane, with 79 per cent. Recent, and are therefore grouped together and treated as Castledilian, though they may contain a few forms from a lower horizon. For the Waitotaran I have taken such published and unpublished records as were available from Waitotara and Patea, the Wairarapa limestone, the Awatere beds, and the Greta beds, omitting the two latter, however, when the correlation of the Greta beds themselves is being discussed below. Finally, I have admitted as intermediate between the Waitotaran and Awamoan the Kawa beds described by Bartrum (1919), together with the basal beds of the Palliser Bay section. The reasons for this will be given more fully below in discussing the Greta beds.

With this basis we may now attack the correlation of the beds of other localities in other diastrophic provinces. The logical procedure in such a province as that in which the Waipara district lies would be first to compile a similar analysis of the range of each species recorded from the Weka Pass stone, the "grey marls," the Mount Brown beds, and the Greta beds in the area within which these rocks can be recognized, and then to compare the lists so obtained with the former list from Oamaru and South Canterbury. If the correlations can be made without reasonable doubt, a combined list will extend further our knowledge of the range of the various species, and so on with the other provinces. This programme involves a great deal of further stratigraphical work and collecting throughout New Zealand, and it will be many years before it can be completely carried out. In the meantime I will show the method as applied to the species known from the district at present under discussion.

Table V gives the lists of species from the various rocks of the district, the Greta beds being also included for convenience. In these columns T signifies that the species was collected by myself, P that it is an additional species from Park's lists of 1905, and H from Hutton's lists of 1885 (B and C) and 1888. For comparison the records in the various stages, compiled as explained above, are also included, S signifying a single record, R that the species is rare (with only two or three records), C that it is common (with four or five records), A that it is abundant, and + and × one or more records.

* They include *Gilbertia paucisulcata* (Marshall), which Mr. Suter determined in my collections from the Waihao greensands.

TABLE V.—RANGE OF TERTIARY MOLLUSCS FROM THE DISTRICT.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
* <i>Amphidesma australe</i> (Gmel.) ..	..	..	!	..	..	T	..	..	S	..	..	..	..	×	×
*—— <i>ventricosum</i> (Gray) ..	..	..	..	..	..	H	..	..	..	..	..	..	..	..	×
<i>Ampullina miocaenica</i> Sut. ..	..	T	..	..	..	..	..	..	S	..	..	R	..	..	..
—— <i>suturalis</i> (Hutt.) ..	..	..	..	..	T	..	+	C	R	S	..	A	..	×	..
<i>Amusium zitteli</i> (Hutt.) ..	..	T	..	..	..	..	..	..	S	S	..	S	..	×	..
* <i>Ancilla australis</i> (Sow.) ..	..	..	..	..	..	T	..	..	S	..	..	A	..	×	×
—— <i>hebra</i> (Hutt.) ..	..	..	..	P	..	T	..	..	R	..	..	A	×	×	×
*—— <i>mucronata</i> (Sow.) ..	..	..	..	..	..	T	..	..	S	..	..	A	×	×	×
*—— <i>novae-zelandiae</i> (Sow.) ..	..	..	..	..	T	T	+	A	..	..	..	A	×	×	..
—— <i>papillata</i> (Tate) ..	..	..	..	T	T	..	..	R	..	R	..	A	..	×	..
*—— <i>pyramidalis</i> (Reeve) ..	..	..	..	..	..	T	..	..	..	..	..	S	..	×	×
* <i>Anomia furcata</i> Sut. ..	..	..	..	T	..	..	..	..	..	..	..	..	..	..	..
*—— <i>huttoni</i> Sut. ..	..	..	..	T	..	T	..	..	R	..	S	C	..	×	×
*—— <i>trigonopsis</i> Hutt. ..	..	..	T	T	T	..	..	..	R	..	..	C	..	×	..
<i>Antigona sulcata</i> (Hutt.) ..	..	..	..	..	T	..	..	..	S	..	..	R	..	×	×
*—— <i>zelandica</i> (Gray) ..	..	..	..	..	..	T	..	..	..	..	..	A	×	×	×
* <i>Arcopagia disculus</i> (Desh.) ..	..	..	..	..	T	T	..	..	..	..	..	..	..	×	×
<i>Athleta huttoni pseudorarisipina</i> Sut. ..	..	..	..	..	..	T?	..	..	..	..	..	..	..	..	..
<i>Aturia australis</i> McCoy ..	H	..	..	P	..	..	..	..	R	S	..	..	..	..	..
* <i>Barnea similis</i> (Gray) ..	..	..	..	..	..	T	..	..	..	..	..	..	×	×	×
—— <i>tiara</i> Tate ..	..	..	..	..	..	T	..	..	..	..	..	..	×	×	×
* <i>Calliostoma punctulatum</i> (Mart.) ..	..	..	..	..	..	P	..	..	..	..	..	..	×	×	×
* <i>Cantharidus tenebrosus</i> A. Ad. ..	..	..	..	..	..	H	..	..	..	..	S	S	..	×	×
* <i>Cerithidea bicarinata</i> (Gray) ..	..	..	..	..	..	T	..	..	..	..	..	..	×	×	×
<i>Cerithiella</i> n. sp. ..	..	..	..	..	..	T	..	..	..	..	..	..	×	×	×
<i>Chione chiloensis</i> (Phil.) ..	..	..	..	..	..	T	..	..	..	..	..	R	..	×	×
—— <i>meridionalis</i> (Sow.) ..	..	..	..	P	..	T	..	..	A	R	C	A	×	×	×
*—— <i>stutchburyi</i> (Gray) ..	..	..	..	..	T	T	..	..	..	..	..	A	×	×	×
*—— <i>yatei</i> (Gray) ..	..	..	..	..	..	T	..	..	..	..	..	S	..	×	×
* <i>Cochloidesma angasi</i> (C. & F.) ..	..	..	..	..	T	..	..	..	..	..	..	S	..	×	×
* <i>Cominella adspersa</i> (Brug.) ..	..	..	..	..	..	T	..	..	..	..	..	..	×	×	×
*—— <i>quoyana</i> (A. Ad.) ..	..	..	..	..	..	T	..	..	..	..	..	R	..	×	×
<i>Corbula canaliculata</i> Hutt. ..	..	T	..	..	..	..	..	..	A	..	..	A	..	×	×
<i>Crassatellites attenuatus</i> (Hutt.) ..	..	..	..	..	T	..	..	..	..	..	..	C	×	×	×
*—— <i>obesus</i> (A. Ad.) ..	..	..	..	P	..	..	..	..	A	..	C	A	..	×	×
* <i>Crepidula costata</i> (Sow.) ..	..	..	..	..	..	T	..	..	..	..	..	C	×	×	×
—— <i>gregaria</i> Sow. ..	..	..	..	..	..	T	..	..	S	..	S	A	×	×	×
*—— <i>monoxyla</i> (Less.) ..	..	..	..	P	T	T	..	..	S	S	..	A	×	×	×
—— <i>striata</i> Hutt. ..	..	..	..	..	T	T	..	..	S	S	..	A	×	×	×
<i>Cucullaea alta</i> Sow. ..	..	..	..	P	..	H?	×	+	R	S	R	A	..	..	..
—— var. B ..	..	..	..	..	T	..	..	..	S	..	..	S	..	..	..
* <i>Cymatium spengleri</i> (Chemn.) ..	..	..	..	..	..	P	..	..	..	..	..	..	×	×	×
<i>Dentalium mantelli</i> Zitt. ..	..	..	..	P	..	..	×	+	C	A	S	A	..	×	×
—— <i>solidum</i> Hutt. ..	T	..	..	..	T	T	..	..	A	C	C	A	×	×	×
* <i>Diplodon zelandica</i> (Gray) ..	..	T	..	..	..	T	..	..	..	R	S	..	×	×	×
* <i>Dosinia anus</i> Phil. ..	..	..	..	..	..	P	..	..	..	..	..	..	×	×	×
*—— <i>greyi</i> Zitt. ..	..	..	..	P	T	T	×	..	A	..	..	A	..	×	×
*—— <i>lambata</i> (Gould) ..	..	..	..	..	..	H	..	..	..	..	..	R	..	×	×
—— <i>magna</i> Hutt. ..	..	..	..	P	..	..	..	..	S	..	..	R	×	×	×
*—— <i>subrosea</i> (Gray) ..	..	..	..	..	..	T	..	..	..	..	..	R	×	×	×
<i>Drillia wanganuiensis</i> Hutt. ..	..	..	..	..	..	H	..	..	..	..	..	S	..	×	×
<i>Epitonium lyratum</i> (Zitt.) ..	T	..	..	P	..	..	..	+	C	C	C	A	..	..	..
—— <i>rotundum</i> Hutt. ..	H	..	..	..	..	..	..	..	..	..	..	..	..	..	..
<i>Euthria media</i> (Hutt.) ..	T?	..	..	..	..	..	..	..	..	S	..	S	..	..	..
* <i>Evarne lineæ</i> (Mart.) ..	..	..	..	..	..	..	..	..	..	..	..	..	..	×	×
* <i>Fusinus spiralis</i> (A. Ad.) ..	..	..	..	..	..	H	..	..	..	..	..	A	..	×	×
<i>Galeodea senex</i> (Hutt.) ..	H	..	..	P	T	..	+	S	S	S	S	A	×	×	×
—— <i>sulcata</i> (Hutt.) ..	..	..	..	..	T	..	..	..	..	..	..	..	..	×	×
* <i>Gari lineolata</i> Gray ..	..	..	..	P	..	T	..	..	A	S	S	A	×	×	×
<i>Glycymeris cordata</i> (Hutt.) ..	..	..	..	..	..	H	..	..	S	..	S	R	..	×	×
—— <i>globosa</i> (Hutt.) ..	..	..	..	P	..	T	..	..	S	..	..	C	×	×	×
*—— <i>laticostata</i> (Q. & G.) ..	..	..	..	..	..	T	..	..	R	S	S	C	..	×	×

TABLE V.—RANGE OF TERTIARY MOLLUSCS FROM THE DISTRICT.—continued.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
* <i>Glycymeris modesta</i> (Angas) ..	..	..	..	P	..	..	..	..	..	..	..	..	..	..	×
<i>Hinnites trailli</i> Hutt. ..	..	..	..	..	T	..	..	..	..	..	..	S	..	..	..
* <i>Ischnochiton maorianus</i> Iredale ..	..	..	..	..	..	T	..	..	..	..	..	..	..	..	..
* <i>Lima bullata</i> (Born.) ..	..	..	..	..	..	..	..	..	..	R	S	S	..	..	×
— <i>colorata</i> Hutt. ..	..	..	..	T	T	..	..	..	S	..	C	A	×	..	..
— <i>imitata</i> Sut. ..	T	..	..	..	..	..	..	..	..	..	..	..	..	..	..
— <i>laevigata</i> Hutt. ..	H	..	..	P	..	..	..	..	S	S	S	..	..	..	..
* — <i>lima</i> (L.) ..	..	..	..	T	..	..	..	..	..	S	S	..	..	..	×
— <i>paleata</i> Hutt. ..	..	..	..	P	T	..	..	..	R	R	C	..	..	..	..
— <i>paucisulcata</i> Hutt. ..	..	..	..	T	T	..	..	..	S	..	..	S	..	..	..
* <i>Limopsis aurita</i> (Brocchi) ..	T	T	..	..	..	×	..	..	A	S	S	A	..	..	..
— <i>insolita</i> (Sow.) ..	..	..	..	P	..	..	..	..	..	..	..	..	..	..	..
— <i>zitteli</i> Iher. ..	..	..	..	..	T	..	+	S	..	C	A	..	..	..	..
<i>Lutraria solida</i> Hutt. ..	..	..	..	..	..	T	..	..	..	..	..	×	×	..	..
<i>Macrocallista assimilis</i> (Hutt.) ..	..	..	..	..	..	P	..	..	R	..	R	C	×	×	×
* — <i>multistriata</i> (Sow.) ..	..	..	..	..	..	P	..	..	S	..	S	A	×	×	×
* <i>Mastra discors</i> Gray ..	..	..	..	..	..	P	..	..	..	..	..	R	×	×	×
— <i>dubia</i> (Hutt.) ..	..	..	..	..	..	T	..	..	..	..	..	R	×	×	×
* <i>Malletia australis</i> (Q. & G.) ..	..	T	..	..	..	..	..	..	S	..	R	A	..	×	×
* <i>Mangilia amoena</i> (Smith) ..	..	..	..	P	..	..	..	..	..	..	..	R	×	×	×
* — <i>sinclairi</i> (E. A. Smith) ..	..	..	..	..	..	T	..	..	..	..	..	S	×	×	×
* <i>Modiolus australis</i> (Gray) ..	..	..	..	..	..	T	..	..	..	..	R	C	×	×	×
* <i>Musculus impactus</i> (Herm.) ..	..	..	..	..	..	T	..	..	..	..	..	..	×	×	×
* <i>Mytilus canaliculus</i> Mart. ..	..	..	..	..	..	T	..	..	..	..	..	..	×	×	×
* — <i>magellanicus</i> Lamk. ..	..	..	..	P?	..	..	..	..	..	..	..	..	×	×	×
* <i>Natica australis</i> (Hutt.) ..	..	..	..	..	T	..	×	..	S	..	..	C	×	×	×
* — <i>zelandica</i> Q. & G. ..	..	..	..	..	..	H	+	R	..	S	A	×	×	×	×
* <i>Neothais succincta</i> (Mart.) ..	..	..	..	..	..	P	..	..	..	..	..	×	×	×	×
<i>Nucula sagittata</i> Sut. ..	..	..	T	..	..	×	..	S	S	S	R	..	..	..	..
<i>Olivella neozelandica</i> (Hutt.) ..	..	..	..	..	..	H	..	..	..	..	S	×	×	×	×
* <i>Ostrea angasi</i> Sow. ..	..	..	T	T	T	..	..	..	..	..	R	×	×	×	×
— <i>arenicola</i> Tate ..	..	..	..	..	..	T	..	..	..	..	..	×	×	×	×
* — <i>corrugata</i> Hutt. ..	..	..	..	..	..	T	..	..	C	..	S	..	×	×	×
— <i>gudexi</i> Sut. ..	..	..	..	T?	..	..	..	..	R	..	..	..	×	×	×
— <i>ingens</i> Zitt. ..	..	..	..	..	..	T	..	..	..	..	..	×	×	×	×
— <i>manubriata</i> Tate ..	..	..	..	..	..	T	..	..	..	..	..	×	×	×	×
— <i>nelsoniana</i> Zitt. ..	..	..	..	..	..	T	..	..	S	S	S	S	×	×	×
* — <i>tatei</i> Sut. ..	..	..	..	..	..	T	..	..	S	..	..	S	×	×	×
— <i>wuellerstorfi</i> Zitt. ..	..	..	..	P	..	..	+	..	..	..	..	×	×	×	×
<i>Panope orbita</i> (Hutt.) ..	..	..	..	P	..	P	×	..	R	S	C	A	×	×	×
<i>Paphia curta</i> (Hutt.) ..	..	..	T	..	..	..	..	..	..	..	R	A	×	×	×
* — <i>intermedia</i> (Q. & G.) ..	..	..	..	..	..	P	..	..	..	..	..	×	×	×	×
<i>Pecten beethami</i> Hutt. ..	..	..	T	T	..	..	..	..	S	..	A	S	..	..	..
— var. B ..	H	..	T	..	..	..	..	..	..	..	..	..	..	..	..
— <i>burnetti</i> Zitt. ..	..	..	..	T	T	..	..	..	..	S	S	S	×	×	×
— <i>crawfordi</i> Hutt. ..	..	..	..	..	T	..	..	..	..	..	..	×	×	×	×
— <i>diffusus</i> Hutt. ..	..	..	..	..	..	H	..	..	..	..	..	..	..	..	..
— <i>fischeri</i> Zitt. ..	H	..	..	..	..	..	..	..	..	..	..	R	..	..	..
— <i>hochstetteri</i> Zitt. ..	..	..	..	..	T	..	..	..	S	..	..	S	..	..	..
— <i>hutchinsoni</i> Hutt. ..	..	..	..	P	..	..	..	..	S	..	A	S	..	..	..
— <i>huttoni</i> (Park) ..	T	T	T	T	T	..	+	A	C	A	A	..	..	..	..
— <i>palmipes</i> Tate ..	..	..	T	..	..	..	..	..	..	..	..	..	..	..	..
* — <i>radiatus</i> Hutt. ..	..	..	..	..	..	P	..	..	..	..	R	S	×	×	×
— <i>triphooki</i> Zitt. ..	..	..	..	..	T?	..	..	..	..	R	..	..	×	×	×
— <i>williamsoni</i> Zitt. ..	H	..	..	P	T	..	..	..	..	..	..	×	×	×	×
* — <i>zelandiae</i> Gray ..	..	..	..	T	..	P	..	..	..	..	..	S	×	×	×
— n. sp. ..	..	..	..	T	..	..	..	..	..	..	..	..	×	×	×
<i>Phos incisus</i> (Hutt.) ..	..	..	..	..	..	P	..	..	..	..	..	..	×	×	×
<i>Placunanomia incisura</i> Hutt. ..	..	..	..	..	T	..	..	..	..	S	S	A	..	..	..
<i>Pleurotomaria tertiaria</i> McCoy ..	H	..	..	..	..	..	..	..	R	S	..	..	..	..	..
<i>Polinices gibbosus</i> (Hutt.) ..	..	..	..	P	T	P	×	..	A	S	R	A	×	×	×

TABLE V.—RANGE OF TERTIARY MOLLUSCS FROM THE DISTRICT—continued.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
<i>Polinices ovatus</i> (Hutt.) ..	..	..	..	..	..	T	..	..	R	R	R	A	×	×	×
<i>Protocardia alata</i> Sut. ..	..	..	..	..	T	..	..	..	..	..	..	..	..	..	..
*— <i>pulchella</i> (Gray) ..	..	..	..	..	..	T	×	..	R	S	R	R	..	..	..
<i>Rissoina vana</i> (Hutt.) ..	..	..	..	..	..	T	..	..	..	..	..	S	×	×	..
* <i>Seila chathamensis</i> Sut. var. ..	..	..	..	..	..	T	..	..	..	..	..	..	..	..	..
* <i>Sigapatella novae-zelandiae</i> (Less.) ..	..	..	..	P	T	T	..	..	R	R	R	A	×	×	×
*— <i>tenuis</i> (Gray) ..	..	..	..	..	..	T	..	..	..	..	..	C	×	×	×
* <i>Spisula aequilateralis</i> (Desh.) ..	..	..	..	..	..	T	..	..	..	..	..	..	×	×	..
<i>Struthiolaria cincta</i> Hutt. ..	..	..	..	..	..	H	..	..	A	S	..	A	×	×	..
*— <i>papulosa</i> (Mart.) ..	..	..	..	..	..	T	..	..	S	..	..	C	×	×	×
— <i>spinosa</i> Heet. ..	T	..	..	..	..	..	..	..	..	..	..	S	..	..	..
— <i>tuberculata</i> Hutt. ..	..	..	T	..	..	..	..	..	R	..	R	A	..	..	..
<i>Surcula fusiformis</i> Hutt. ..	..	..	..	..	..	T	×	..	A	S	S	A	×	×	..
<i>Taron brevirostris</i> (Hutt.) ..	..	..	..	..	..	T	..	..	..	..	..	A	..	..	..
* <i>Tellina deltoidalis</i> Hutt. ..	..	..	..	..	..	T	..	..	..	..	..	..	×	×	..
*— <i>eugonia</i> Sut. ..	..	..	..	P	T	..	..	..	R	..	..	..	×	×	..
* <i>Terebra tristis</i> Desh. ..	..	..	..	..	..	T	..	..	R	..	..	R	×	×	..
<i>Teredo heaphyi</i> Zitt. ..	T	..	..	..	..	×	..	..	A	C	C	A	..	..	..
<i>Thracia</i> n. sp. ..	..	..	..	..	T	..	..	..	..	..	..	..	..	..	..
<i>Trochus conicus</i> (Hutt.) ..	..	..	..	..	..	T	..	..	..	S	..	..	×	×	..
*— <i>tiaratus</i> Q. & G. ..	..	..	..	..	..	T	..	..	..	..	..	C	×	×	..
* <i>Trophon corticatus</i> (Hutt.) ..	..	..	..	..	..	T	..	..	..	..	..	..	×	×	..
<i>Turris altus</i> (Harris) ..	T	..	..	..	..	..	..	..	..	..	..	A	..	..	..
* <i>Turritella carlottae</i> Wats. ..	..	T	..	..	..	..	..	..	A	R	..	A	×	×	×
— <i>cavershamensis</i> Harris ..	..	..	..	P	..	..	..	..	A	..	..	A	..	..	..
— <i>concava</i> Hutt. ..	..	..	..	..	T	..	..	..	R	..	R	A	..	..	..
*— <i>rosea</i> Q. & G. ..	..	..	..	..	..	P	..	..	..	..	..	..	×	×	×
*— <i>symmetrica</i> Hutt. ..	..	..	..	..	..	H	×	+	R	S	..	C	×	×	×
* <i>Umbonium zelandicum</i> (H. & J.) ..	..	..	..	..	..	P	..	..	..	..	..	..	×	×	×
* <i>Venericardia difficilis</i> (Desh.) ..	..	..	..	..	..	T	..	..	A	R	S	A	×	×	×
*— <i>purpurata</i> (Desh.) ..	..	..	..	..	T	T	..	..	R	S	C	A	×	×	×
* <i>Verconella caudata</i> (Q. & G.) ..	..	..	..	..	..	H	..	..	..	..	..	S	×	×	×
— <i>costata</i> (Hutt.) ..	..	T	..	..	T	..	..	..	R	S	..	A	×	..	..
*— <i>dilatata</i> (Q. & G.) ..	..	..	..	..	T	T	..	..	S	..	R	A	×	×	×
*— <i>mandarina</i> (Duclos) ..	..	..	..	..	..	T	..	..	R	..	..	S	×	×	×
*— <i>nodosa</i> (Mart.) ..	..	..	..	P	..	..	+	C	S	..	A	..	×	×	×
— <i>orbata</i> (Hutt.) ..	..	..	..	..	..	P	..	..	..	..	..	..	×	×	..
*— <i>attenuata</i> Hutt. ..	H	..	..	..	..	..	..	..	..	..	..	..	..	..	..
<i>Voluta arabica</i> Mart. ..	..	..	..	..	T	T	..	..	R	..	..	A	×	×	×
— <i>corrugata</i> Hutt. ..	..	..	..	P	..	T	+	R	R	R	A	..	×	×	×
*— <i>elongata</i> Swains. ..	..	..	..	P	..	..	..	..	..	..	..	A	..	×	×
— sp. cf. <i>protorhysa</i> Tate ..	T	..	..	..	T	..	..	..	..	..	..	..	..	..	..
* <i>Zenatia acinaces</i> (Q. & G.) ..	..	..	..	..	..	P	..	..	S	S	S	A	×	×	×
Total number of species, 166 ..	19	9	8	45	43	95									
Number of Recent species ..	1	3	1	18	15	64									
Percentage of Recent species ..	5	33	12½	40	34	67									

Column.

1. Weka Pass stone.
2. "Grey marls."
3. Lower Mount Brown beds (below limestone D).
4. Main Mount Brown limestone (D).
5. Uppermost Mount Brown beds (E).
6. Greta beds.
7. Wangaloa fauna from Marshall (1917c).
8. Hampden beds from Marshall (1919).

Column.

9. Waiarekan stage of Oamaru and South Canterbury.
10. Ototaran stage of Oamaru and South Canterbury.
11. Hutchinsonian stage of Oamaru and South Canterbury.
12. Awamoan stage of Oamaru and South Canterbury.
13. Kawa Creek beds from Bartrum (1919) and Palliser Bay basal beds.
14. Waitotaran stage.
15. Castlecliffian stage.

If we now calculate the percentage of records in the various stages, using the method of implication, we obtain the following results:—

TABLE VI.

	1	2	3	4	5	6	7
Percentage recorded from Wangaloa and Hampden beds	26	19	22	12	20	26	11
Percentage recorded from Waiarekan ..	42	50	88	62	66	60	38
Percentage recorded from Ototaran ..	52	58	100	62	75	69	42
Percentage recorded from Hutchinsonian ..	42	54	100	75	73	69	46
Percentage recorded from Awamoan ..	52	61	100	75	80	83	69
Percentage recorded from Kawa Creek beds ..	10	23	44	25	58	53	70
Percentage recorded from Waitotaran ..	5	19	44	25	49	49	69*
Percentage recorded from Castlecliffian ..	5	15	33	13	40	37	77
Percentage of Recent species ..	5	15	33	13	40	34	67

* In calculating this percentage the records from the Greta and Awatere beds were excluded and only those from the North Island localities, or records by implication, were used.

- | | |
|---|-------------------------------------|
| 1. Weka Pass stone. | 4. Lower Mount Brown beds. |
| 2. Weka Pass stone and "grey marls" combined. | 5. Main Mount Brown limestone. |
| 3. "Grey marls." | 6. Uppermost Mount Brown limestone. |
| | 7. Greta beds. |

It will be seen that the analysis favours the correlation of all the beds up to the top of the Mount Brown limestone with the upper Oamaruan, and, if we group together the Weka Pass stone and "grey marls," of all with the Awamoan. Against this we have the positive evidence of the Foraminifera that the Weka Pass stone and "grey marls" are lower than Ototaran, and of the brachiopods that the main Mount Brown limestone is Hutchinsonian. It is obvious, therefore, that the range of the Mollusca is not yet sufficiently known to give confidence in its use in correlation, which tends unduly to favour correlation with the Awamoan.

If we examine in detail the list of species from the Weka Pass stone, we find that the species which are responsible for the relatively high value of the Awamoan records are only three—viz., *Struthiolaria spinosa*, *Turris altus*, and *Pecten fischeri*—all recorded from the Awamoan only. The finding of any two of these, or of the species without any record—viz., *Epitonium rotundum*, *Lima imitata*, *Pecten beethami* var. B, *Pecten williamsoni*, *Voluta attenuata*, and *Voluta* sp. cf. *protorhysa* Tate—in the Waiarekan or lower beds would bring the percentage of Waiarekan species up to that of the Awamoan.

The collections are scarcely large enough to use the percentage of Recent species with confidence. This method would place the Weka Pass stone with the Wangaloa and Hampden beds, the "grey marls" with the Ototaran, the middle Mount Brown beds again with the Wangaloa and Hampden beds, the main Mount Brown limestone and the uppermost Mount Brown limestone in the Hutchinsonian or Ototaran. A curious coincidence in the percentages is that the uppermost limestone shows a lower percentage than the main Mount Brown limestone, just as do the Target Gully beds compared to the upper Hutchinsonian in Target Gully, and the total Awamoan fauna compared to the total Hutchinsonian fauna of Oamaru and South Canterbury. In the present case little stress can be laid upon this point, as the list from the main Mount Brown limestone contains so many species collected by Park in 1905 from an horizon not quite definitely determined.

There is still another way in which the molluscan evidence can be looked at—viz., from the point of view of the range of the species within the district. Thus *Pecten huttoni* and *Dentalium solidum* range through

the 900 or more feet of strata from the Wēka Pass stone to the uppermost Mount Brown beds, and in Oamaru range through a similar thickness of beds which probably formed at much the same rate. This suggests that the whole of the Oamaruan is represented in the Waipara sequence, and that the Wēka Pass stone correlates with the Ngaparan and Waiarekan, and the uppermost Mount Brown beds with the Awamoan.

The general conclusion to be derived from the evidence of the Mollusca is, then, that taken by itself it is not conclusive as to exact correlation with Oamaruan stages, and does not stand in the way of the positive correlations demanded by the brachiopods and Foraminifera.

The range of the brachiopods occurring in the district is shown in the following table:—

TABLE VII.—RANGE OF TERTIARY BRACHIOPODS FROM THE DISTRICT.

—	1	2	3	4	5	6	7	8	9	10
<i>Aetheia gaulteri</i> (Morris) ..	×	..	..	..	..	W	O	H	A	..
<i>Hemithyris nigricans</i> (Sow.)	..	..	..	..	×	..	..	H	A	W
<i>Terebratulina suessi</i> (Hutt.)	..	..	..	+	..	W	O	H	..	..
<i>Terebratulina cf. cancellata</i> Koch	..	..	..	+	..	..	..	..	..	..
<i>Bouchardia minima</i> Thomson	..	..	..	+	..	..	O	..	..	..
<i>Magadina waiparensis</i> Thomson	..	..	×	..	..	..	..	..	..	..
— <i>browni</i> Thomson	..	..	..	+	×	..	..	..	..	..
<i>Rhizothyris curiosa</i> Thomson	..	..	..	..	×	..	O	..	..	..
— <i>media</i> Thomson	..	..	..	..	×	..	..	..	..	..
— <i>scutum</i> Thomson	..	..	..	+	×	..	O	H	..	..
— <i>rhizoida</i> (Hutt.)	..	..	..	+	..	..	..	H	..	..
— <i>elongata</i> Thomson	..	..	..	+	..	..	..	H	..	..
— <i>curta</i> Thomson	..	..	..	+	×	..	O	H	..	..
— <i>crassa</i> Thomson	..	..	..	+	..	..	..	..	..	..
— <i>elliptica</i> Thomson	..	..	..	+	×	..	O	H	..	..
— <i>fortis</i> Thomson	..	..	..	+	×	..	..	..	..	..
— <i>obesa</i> Thomson	..	..	..	+	×	..	..	..	..	..
— <i>lateralis</i> Thomson	..	..	..	?	?	..	..	..	..	..
— <i>pirum</i> Thomson	..	..	..	+	..	..	..	..	..	..
— <i>ovata</i> Thomson	..	..	..	+	..	..	O	H	..	..
— <i>amygdala</i> ..	..	..	..	cf.	..	..	..	H	..	..
<i>Pachymagas cottoni</i> Thomson	..	..	..	+	×	..	..	H	..	..
— <i>bartrumi</i> Thomson	..	..	..	+	..	..	..	..	..	..
— <i>clarkei</i> Thomson	..	+	..	..	..	..	..	..	..	..
— <i>huasti</i> Thomson	..	..	..	+	..	..	O	H	..	..
— <i>hectori</i> Thomson	..	..	..	+	×	..	O	H	..	..
— <i>parki</i> (Hutt.)	..	..	..	+	..	..	..	H	..	..
— <i>McKayi</i> Thomson	..	..	..	+	..	..	..	..	..	..
— <i>morgani</i> ..	..	..	..	+	..	..	..	..	..	..
— <i>coxi</i> Thomson	..	..	..	+	..	..	..	..	..	..
— <i>huttoni</i> Thomson	..	+	..	..	..	..	O	H	..	..
— <i>andrewi</i> Thomson	..	..	..	..	×	..	..	..	..	..
<i>Waiparia abnormis</i> (Thomson)	..	..	..	+	..	..	..	..	A	..
— <i>intermedia</i> Thomson	..	..	..	+	..	..	?	..	A	..
<i>Neothyris campbellica</i> (Filhol)	..	..	..	..	×	..	..	..	..	W
— <i>ovalis</i> (Hutt.)	..	..	..	..	×	..	..	..	..	W
— <i>novara</i> (Iher.)	..	..	..	..	×	..	..	..	..	..
— <i>iheringi</i> Thomson	..	..	..	..	×	..	..	..	..	..
— <i>anceps</i> Thomson	..	..	..	..	×	..	..	..	..	..
<i>Stethothyris sufflata</i> (Tate) ..	..	..	..	..	×	..	..	..	..	..

Column.

1. Wēka Pass stone.
2. Lowest Mount Brown limestone (C).
3. Second Mount Brown limestone.
4. Main Mount Brown Limestone (D).
5. Uppermost Mount Brown beds.

Column.

6. Waiarekan.
7. Ototarān.
8. Hutchinsonian.
9. Awamoan.
10. Wanganuiān.

The letters in columns 6–10 are the initials of the stage-names, which help to guide the eye better than an asterisk.

Owing to the fact that so few brachiopods are recorded from the Waiarekan and the Awamoan elsewhere, the percentage of records of the Waipara species from the various Oamaruan stages, though favouring the correlation of the main Mount Brown limestone with the Hutchinsonian, is little more conclusive than in the case of the molluscs. It is shown in the following table :—

TABLE VIII.

	1	2
Percentage of species recorded from Waiarekan	4	0
Percentage of species recorded from Ototaran	32	28
Percentage of species recorded from Hutchinsonian	48	33
Percentage of species recorded from Awamoan	8	6
Percentage of species recorded from Wanganuian	0	16
Percentage of species not recorded elsewhere	40	44

1. Main Mount Brown limestone (D).
2. Uppermost Mount Brown beds.

When the affinities of the species not recorded elsewhere are taken into consideration, the case for the correlation of the main Mount Brown limestone with the Hutchinsonian, and for the uppermost Mount Brown beds with the Awamoan, becomes much stronger. The fauna of the former horizon consists entirely of species closely related to Hutchinsonian forms, with the exception only of *Bouchardia minima*, known elsewhere only from the Ototaran, and *Magadina browni*, not known in the southern Oamaruan localities. The fauna of the uppermost Mount Brown beds contains characteristic large species, not easily overlooked, which are absent from the southern Oamaruan localities—viz., *Stethothyris sufflata*, *Neothyris novara*, *N. iheringi*, and *N. anceps*—suggesting that either this horizon is unrepresented at Oamaru, or that it does not there yield brachiopods, which is the case with the Awamoan, while the Hutchinsonian affinities of part of the remainder, mainly *Rhizothyris*, are offset by the Wanganuian affinities of another part, *Hemithyris* and *Neothyris*.

The species of *Rhizothyris* and *Pachymagas* which range from the main Mount Brown limestone into the overlying beds consist for the most part of species not so advanced as regards elongation and folding as those confined to the main limestone. The explanation seems to be that the more primitive stocks had a longer range, while the more highly evolved forms, possessing no further potentialities of evolution, were narrowly restricted in time. The occurrence of the two species *Rhizothyris elongata* and *Pachymagas parki* only in the Hutchinson Quarry greensand and in the main Mount Brown limestone would of itself favour the correlation of these two beds, but when the advanced nature of their evolution is taken into account it enormously strengthens the case for the correlation. Combining all three points of view, we may conclude that the evidence is sufficiently strong to support definitely the correlation of the main Mount Brown limestone with the Hutchinsonian and of the uppermost beds with the Awamoan. The evidence of the brachiopods as to the correlation of the beds below the main limestone is inconclusive.

Combining all lines of evidence, we find the following correlations indicated :—

- Uppermost Mount Brown beds—Awamoan.
- Main Mount Brown limestone—Hutchinsonian.
- Lower Mount Brown beds—Ototaran.
- "Grey marls" and Weka Pass stone—Waiarekan.

WANGANUIAN.

The Greta beds have a wide distribution in the neighbouring Lower Waipara, Upper Waipara, Greta, and Motunau districts, where the nature of the beds and of the fossils are generally similar to those of the Middle Waipara and Weka Pass. They are also known to occur in the Oaro Valley, near Amuri Bluff. No considerable collections of any extent or recently named are available from any of these localities. In 1913 I collected carefully from the Greta beds of the Lower Waipara, but obtained only twenty-seven species, of which twenty, or 74 per cent., are Recent species. The extinct species were *Calliostoma waiparensis*, *Crepidula gregaria*, *Lutraria solida*, *Pecten triphooki*, *P. crawfordi*, *Ostrea arenicola*, and *O. nelsoniana* (?).

Owing to the absence of a comprehensive list of Waitotaran fossils from the typical locality, the percentages of records of the various stages shown in Table VI favours correlation of the Greta beds rather with the Castlecliffian than with the Waitotaran, but the presence of such forms as *Ostrea ingens* suggests that the true correlation is with the Waitotaran. With this the percentage of Recent species, 67 per cent., is also more in accord. Marshall gives 60–70 per cent. for the Waipipi series, which apparently includes the Waitotaran, and 80–90 per cent. for the Castlecliff series. Final decision as to correlation of the Greta beds must be postponed until lists from the Wanganui-Patea districts are available.

Only a small number of species are common to the Greta and Awatere beds, although the latter have usually been correlated with the former. Park (1905) obtained forty-two species from the Starborough Creek beds, of which 71 per cent. were Recent; from the same beds I obtained fifty-seven species, of which only 51 per cent. were Recent. The two lists combined give seventy-seven species, of which 60 per cent. are Recent.

Marshall (1919) has suggested that the Greta and Awatere beds may occupy a position intermediate between the Target Gully series (Awamoan, with 30–40 per cent. of Recent species) and the Waipipi series (Waitotaran, with 60–70 per cent. of Recent species). The list of species from the Greta beds, numbering ninety-five, with 67 per cent. of Recent species, is now sufficiently extensive to make it very improbable that the suggestion is correct. In the Middle Waipara district the Greta beds follow directly upon the uppermost Mount Brown beds, with only 34 per cent. of Recent species, and the sudden doubling of this percentage gives a strong presumption of unconformity. If beds bridging the palaeontological gap can be found in any other part of New Zealand the evidence for unconformity will be conclusive.

In 1913 I pointed out that the Starborough Creek beds of the Awatere Valley were underlain by a great thickness of beds, in the lower parts of which Miocene (*i.e.*, Oamaruan) types such as *Cucullaea* and *Limopsis* occurred. The collection from Tatchell's Creek was not in very satisfactory condition, but yielded *Ancilla* sp., *Cardium spatiosum* Hutt.?, *C. maorinum* Sut.?, *Chione meridionalis* (Sow.)?, *Cominella lurida* (Phil.), *Dentalium solidum* Hutt., *Leda semiteres* Hutt.?, *Limopsis aurita* (Brocchi), *L. catenata* Sut., *Maculopepium elegantissimum* (Sut.)?, *Mytilus striatus* Hutt., *Ostrea angasi* Sow.?, *Panope orbita* (Hutt.), *Pecten huttoni* (Park), *Struthiolaria cincta* Hutt.?, *S. tuberculata* Hutt., *Turritella symmetrica* Hutt.?, *Verconella dilatata* (Q. & G.)?, and *Voluta corrugata* Hutt. This fauna appears to be characteristically Oamaruan, so that if the beds containing it underlie the Awatere series conformably an intermediate fauna should be found.

In 1919 I pointed out that the blue mudstones of the Palliser Bay district, which in their upper part contain a Waitotaran and probably above that also a Castlecliffian fauna, also contain Oamaruan species near the base. Those collected were *Antigona zelandica* (Gray), *Cominella adpersa* (Brug.), *C. purchasi* Sut., *Dosinia anus* (Phil.), *D. subrosea* (Gray), *Dentalium solidum* Hutt., *Galeodea senex* (Hutt.), *Paphia curta* (Hutt.), *Polinices gibbosus* (Hutt.)?, *Struthiolaria tuberculata* var., *S. papulosa* var. While the Oamaruan affinities of this fauna are apparent, three species—viz., *Cominella adpersa*, *C. purchasi*, and *Dosinia anus*—are not known from the Oamaruan of Otago and South Canterbury. It seems quite possible that this fauna will prove to be intermediate between the Awamoan and the Waitotaran.

In 1919 Bartrum also described a series of beds at Kawa Creek which overlie Oamaruan beds unconformably, but contain a fauna with strong Oamaruan affinities, although the percentage of Recent species is 62 in a collection of 74 species. The percentage of records in the various stages is as follows: Wangaloa and Hampden beds, 8; Waiarekan, 42; Ototaran, 50; Hutchinsonian, 54; Awamoan, 64; Waitotaran, 62; Castlecliffian, 68. Probably when a fuller list of Waitotaran species is available for comparison Bartrum's conclusion that the fauna is intermediate between Awamoan and Wanganui will be substantiated.

DIASTROPHIC PROVINCES IN NEW ZEALAND.

In 1917 I discussed the application of diastrophic criteria to the correlation and classification of the younger rocks of New Zealand, and while agreeing with Marshall, Speight, and Cotton (1911) and later expressed views by Marshall on a certain diastrophic unity of all these younger rocks, necessitating the use of an inclusive name, for which I proposed "Notocene," I gave briefly the evidence for the existence of minor diastrophic districts during the general relative crustal inactivity between the great post-Hokonui and Kaikoura deformations. This evidence consisted of the differences in age of the oldest and youngest marine Notocene rocks of different districts, proving differences in the dates of sea-advance and sea-retreat in these districts, and also differences in age of the main limestone member of the sequence in different districts—viz., the Amuri, Ototara, and Takaka limestones—proving that the period of maximum sea-advance was not everywhere contemporaneous. To avoid confusion between geographical and diastrophic districts, I propose now to call the latter "provinces."

Marshall (1919), who appears to have misunderstood the argument, states, "I can reasonably hold that no proof has been given of these supposed local diastrophic movements in New Zealand, and I can quote the Oamaru district, at least, as one in which the Tertiary strata are continuous over a large district without any indication of being affected by local diastrophic action." It is evident that I stated the argument too briefly by omitting to define more explicitly the diastrophic provinces. This omission I remedied last year (1919, p. 310), when I defined the provinces of the east coast of the South Island. The Oamaru geographical district, which is understood as comprising the coastal area between the Kakanui and Waitaki Rivers, but excludes Shag Point, forms, with the adjacent Waitaki, Waihao, Pareora, Kakahu, and Mount Somers districts, a diastrophic province extending from the Kakanui to the Rakaia Rivers, and I quite agree with Marshall that within it there is no diversity of diastrophism exclusive of local volcanic phenomena. Excluding the variations due to the development of volcanic rocks, found chiefly in the Oamaru and Mount Somers districts, the stratigraphical sequence and fossils of these districts are almost identical. The

diastrophic history of the whole of this province appears to have been as follows: Emergence of the pre-Notocene rocks during Clarentian, Piripauan, and Kaitangatan, ending with peneplanation: submergence with sedimentation in the Ngaparan or Waiarekan, attaining its maximum in the Ototaran; a cessation of sedimentation before the deposition of the Hutchinsonian, perhaps due to standstill of land and sea, during which a phosphatization of the upper surface of the Ototara limestone took place; gradually shallowing of the sea during the Hutchinsonian and Awamoan, followed by emergence at the end of the Awamoan; deposition of terrestrial gravels during the Wanganuiian; block-faulting, with tilting of the Oamaruian and Wanganuiian beds about the close of the Wanganuiian.

The Middle Waipara and Weka Pass district, on the other hand, forms part of a diastrophic province extending from the Rakaia River to Kairourou Peninsula. The stratigraphical sequence is not so constant as in the southern province, owing to an overlap traceable in the older beds, and there are still large parts of the province that have not been described in detail. The diastrophic history appears to have been as follows: Emergence of the pre-Notocene rocks during the Clarentian, without complete attainment of peneplanation; partial submergence and sedimentation during the Piripauan and Kaitangatan, with progressive overlap on the diversified surface; a cessation of sedimentation before the deposition of the Oamaruian, probably due to a standstill of land and sea, during which a phosphatization of the Amuri limestone took place; renewed depression of the Amuri limestone and the old land, leading to an overlap of the Weka Pass stone over the Piripauan and Kaitangatan on to the now peneplaned pre-Notocene (lower Oamaruian); shallowing of the Oamaruian sea with oscillations of movement during which the "grey marls" and Mount Brown limestones were deposited, with interformational unconformities (upper Oamaruian); uplifts, perhaps of the nature of block movements, exposing fresh areas of pre-Notocene rocks to rapid erosion, with deposition of the Greta beds (early Wanganuiian); uplifts, with folding or tilting and erosion of the whole marine Notocene, and deposition of the terrestrial Kowhai beds (late Wanganuiian); block-faulting about the close of the Wanganuiian, with renewed folding or tilting of both the marine and terrestrial Notocene series.

The diastrophic histories of these two areas are thus seen to be markedly dissimilar. In the northern province marine beds, both older and younger, are developed which have no counterpart in the southern; the nature of the beds of correlative age (Oamaruian) is different in the two areas; and the relationship of certain beds is different. The greatest difficulty in the geology of each area is the nature of the conditions which permitted phosphatization of the upper surfaces of certain limestones. Whatever these conditions were, they happened at different times in the two provinces. The stratigraphical unity within the boundaries of each province, and the diversity between the two, are salient facts that demand recognition.

Two of the classifications proposed for the younger rocks of New Zealand have failed to recognize the existence of the diversity of stratigraphical and diastrophic history in the above and other provinces—viz., the Cretaceo-Tertiary classification of Hector and the single rock-series classification of Marshall. In each of these a supposed uniformity of stratigraphy has been assumed by the mistaken correlation of the Amuri and Ototara limestones. The majority of the other classifications—those of Hutton, von Haast, Park, Morgan, and Woods—recognize the distinctness of these limestones, and therefore part at least of the diversity of the above provinces, but explain the facts by postulating important earth-movements between

different members of the series, causing unconformities of regional classificatory value. They fail, however, to recognize the grander fact that all the younger rocks were deposited in a period of relative crustal inactivity between the epochs of major diastrophism, and on this account should be grouped into one grand system. This is recognized in the classifications of Marshall and Thomson. Each of the above types of classification will now be examined in detail with regard to its applicability to the palaeontological and stratigraphical facts brought out in this paper, and in relation to the explanation it offers for the diversities exhibited in the three main diastrophic provinces of the east coast of the South Island.

THE CRETACEO-TERTIARY FORMATION OF HECTOR.

It has been stated by Park that the theory of a conformable succession bridging the gap between the Cretaceous and Tertiary in New Zealand was first proposed by Hutton, but later abandoned by him, and was afterwards taken up by Hector. I have failed to discover the evidence for this statement in any of the published writings of Hutton, though Hector (1892) states that when he used the term "Cretaceo-Tertiary" in 1877 it was a revival of a term which had been in abeyance for some years. Hector's adoption of the formation in 1877 appears to be a direct outcome of the views he always held as to the Mesozoic age of all the coalfields in New Zealand. Thus when Provincial Geologist of Otago he classed the marine rocks of Oamaru, Hampden, Caversham, &c., under a 'Tertiary Oamaru series, but the coal-measures of Kaitangata, Clutha, Shag Point, &c., under a Carbonaceous series, and considered it as possibly upper Mesozoic.

In 1870, after he had visited the Waipara district, the North Canterbury rocks now included in the Notocene were grouped by Hector in the *Catalogue of the Colonial Museum* as follows:—

Tertiary	B. Upper or <i>Struthiolaria</i> series	..	..	Motunau, Lower Gorge of the Waipara River.
	C. Middle or <i>Cucullaea</i> series	..	..	Waikari, Lyngdon, Hurunui Mound, Upper Trelickick.
	D. Older or Ototara series	..	..	Deans, Weka Pass, Curiosity Shop, Selwyn River, Lower Trelickick.
Mesozoic	E. <i>Leda</i> marls or Aotea series	..	..	Conway River, Waiau-ua.
	F. Chalk and chalk marls	..	..	(Amuri Bluff).
	G. Ferruginous sandstones or Waipara series			Boby's Creek, Culverden.

In this grouping of the *Leda* marls (which subsequently were termed the "grey marls") with the Chalk or Amuri limestone and the Waipara series in the Secondary as opposed to the Mount Brown beds of the Deans in the Older Tertiary, the Cretaceo-Tertiary formation was clearly foreshadowed. In 1877 Hutton included the "grey marls" in his Oamaru system, and the Amuri limestone and underlying beds in his Waipara system. Hector (1877A), in commenting on Hutton's paper, rejected Hutton's classification, and in a table of beds of Amuri Bluff included the "grey marls" and fucoidal limestone (Weka Pass stone) with the Amuri limestone in a Chalk group, recognizing also two lower groups, which he named the Greensand group and the Amuri group. In the following volume of *Reports of Geological Explorations* (1877B) he used the name of Cretaceo-Tertiary formation for a part of the sequence in the Kaipara district, and in the following volume again (1877C) it appeared for the first time in a general table of New Zealand formations, though not in its final form. The following table shows the various names applied to the divisions or series of the formation.

1877c.	1879.	1884.	1886.	1887c.
<i>a.</i> { Cardita beds, } { Grey marls. } <i>b.</i> Ototara and Weka Pass stone. <i>c.</i> Fucoidal greensands. <i>d.</i> Chalk marls and Amuri limestone. <i>e.</i> Marly greensands. <i>f.</i> Island sandstone (Reptilian beds). <i>g.</i> Coal formation and black grit.	<i>a.</i> Grey marls. <i>b.</i> Ototara and Weka Pass stone. <i>c.</i> Fucoidal greensands. <i>d.</i> Amuri limestone, chalk, marls, and chalk with flints. <i>e.</i> Marly greensands. <i>f.</i> Island sandstone (Reptilian beds). <i>g.</i> Black grit and coal formation	<i>a.</i> Waitemata. <i>b.</i> Ototara. <i>c.</i> Mawhera. <i>d.</i> Chalk. <i>e.</i> Waireka. <i>f.</i> Bobby's Creek. <i>g.</i> Hororata. <i>h.</i> Coal.	<i>a.</i> Grey marls. <i>b.</i> Ototara series. <i>c.</i> Mawhera series. <i>d.</i> Chalk series. <i>e.</i> Waireka series. <i>f.</i> Coal series. <i>g.</i> Black grit series. <i>h.</i> Prophylite breccia series. <i>i.</i> Great conglomerate series.	<i>a.</i> Grey marls. <i>b.</i> Ototara stone. <i>c.</i> Fucoidal greensands. <i>d.</i> Amuri limestone. <i>e.</i> Island sandstone. <i>f.</i> Coal formation of New Zealand. <i>g.</i> Black grit. <i>h.</i> Prophylite breccias. <i>i.</i> Conglomerate.

The beds below the black grit of Amuri Bluff were placed in a distinct Lower Greensand formation, and the horizon of the black grit was correlated with the coal-beds of the Waipara and all the other chief coal-measures of the country. This had the effect of removing from the Cretaceous-Tertiary formation the ammonites, belemnites, *Trigoniae*, &c. found so abundantly in the calcareous conglomerate of Amuri Bluff. In 1892 Hector admitted that the Lower Greensand formation could not be maintained as a distinct formation, and considered it a local expansion of the *Ostrea* bed of the Waipara district, a view later demonstrated to be correct by Woods (1917).

Hector's Cretaceous-Tertiary theory rested on two claims: first, that all the rocks of the Waipara district from the coal-measures up to and including the "grey marls" formed a single conformable "formation" and palaeontological unit, and were separated from the overlying Mount Brown beds by an unconformity; and, secondly, that all the important coal-measures in New Zealand, together with the conformably associated rocks, belonged to the same "formation."

As regards the first claim, Hector appears never to have studied the contact of the Amuri limestone and Weka Pass stone carefully. In his first account of the district he did not discriminate between the two rocks, and after Hutton had made the distinction, and had claimed the contact as an unconformity, emphasizing its palaeontological importance as a plane above which no Cretaceous fossils ranged, and below which no Tertiary fossils occurred, Hector apparently made no special study of the contact, and was content to rely on McKay's attempts to combat Hutton's criticisms. He insisted strongly, however, on the existence of an unconformity between the "grey marls" and the Mount Brown beds, publishing a map of the Weka Pass in support of his contention. The map was, however, little more than a diagram, and does not appear to have been based on a detailed survey. Hector was either unaware of, or ignored, the range of Tertiary Mollusca above and below the unconformity, and made no attempt to analyse their range, contenting himself with a statement of characteristic species from the Cretaceous-Tertiary and higher formations, species which are now known to have a considerable range above or below the rocks he included in each formation.

McKay (1887A) made a more serious attempt to meet Hutton's criticisms. He reaffirmed the conformity of the two rocks on the ground of their parallelism of dip and strike, and attributed the so-called shattering of the Amuri limestone to jointing and a subsequent working-down of the loose greensand into the joint-planes. He endeavoured to refute Hutton's statement that pebbles of Amuri limestone were enclosed in the Weka Pass greensand by publishing an analysis of a phosphatic nodule as a proof that all the supposed pebbles were concretions, and he made a very strained comparison of the pebbles with concretions in the Waipara greensands. From later analyses it is now clear that the analysis quoted by McKay referred to one of the phosphatic concretions found rarely near the contact, and not to the majority of the supposed pebbles, which are only slightly phosphatized, and are undoubtedly fragments of Amuri limestone. McKay also published an analysis of Amuri limestone which showed a high percentage of insoluble residue described as sand, and argued from this that Hutton's statement that the Weka Pass stone overlapped the Amuri limestone on to the old rocks on the neighbouring Mount Alexander Range had no significance, as a sandy limestone might easily pass in a few miles into a sandstone. Here again McKay's analysis has been shown by later chemical study not to be typical of the Amuri limestone. In answer to Hutton's

contention that no Tertiary species were found below the contact McKay published a list of Tertiary species found below the Amuri limestone in North Canterbury and Marlborough. As no descriptions or figures of these species were supplied, and as the statement rested solely on McKay's identifications, it did not gain acceptance, and Woods's later study of the Cretaceous Pelecypoda does not bear it out. It should be noted, however, that Henderson (1918) collected a shell from beds below the Amuri limestone of the Cheviot district which was determined by Suter as *Malletia australis* (Q. & G.). The existence of a few of the wide-ranging Oamaruan Mollusca below the Amuri limestone would not excite surprise, and, though invalidating the absolute truth of Hutton's contention, would not destroy the truth of the claim that the faunas known from the rocks above and below the contact are characteristically distinct. Hector's first claim, that the Cretaceo-Tertiary formation is a satisfactory unit in the classification of the Waipara sequence, has been destroyed by Hutton's criticisms, reinforced by later studies.

It should be noted that von Haast adopted a grouping of the rocks different from those of both Hector and Hutton, and included all the beds from the coal-measures to the top of the Weka Pass stone in a Waipara system of Cretaceo-Tertiary age. The correlations he claimed for this system were those of Hutton's Waipara system and not those of Hector's Cretaceo-Tertiary formation. Park also in 1905 adopted the same grouping as von Haast for his Cretaceous Waipara system, in the mistaken belief that the Weka Pass stone contained no Tertiary fossils. Hutton's criticisms, reinforced as above, are equally valid against these groupings of the Waipara rocks.

Hector's second claim for the correlation in the Cretaceo-Tertiary formation of all the important coal-measures rested on the following general argument:—

"In northern Canterbury, as far south as the Rakaia River, the coal rocks are overlaid by fossiliferous strata, which, besides the Plesiosauroid reptiles for which the Waipara district is famous, contain a few secondary genera, such as *Belemnites*, *Aporrhais*, *Inoceramus*, and *Trigonia*; but the great mass of the associated molluscan fauna agrees with that of the coal rocks in other parts of New Zealand, while the specially Cretaceous forms are rare or absent from the fossiliferous horizons immediately overlying the coal-seams. If, therefore, after eliminating the comparatively few fossils which form the peculiarities of two localities, the bulk of those remaining are found to be the same, there need be no hesitation in considering strata showing the same succession of like characters in its different divisions as belonging to the same series; and, if in any one of these localities there is evidence that the beds are of Cretaceous age, the other must be regarded as of that age also. But if, in addition to this, there be, in those localities where the lower beds lack fossils proving their Cretaceous age, a presence of Cretaceous forms in the higher beds of the same series, the correctness of the correlation will in this way be corroborated. It is partly by evidence of this kind that the Cretaceous age of several of our coal-bearing areas is sought to be established.

"In South Canterbury, on the east coast of Otago, and on the west coast of the South Island markedly, Cretaceous fossils are found in the calcareous members of the higher part of the coal-bearing series. The Cretaceous character of the Echinodermata found in the Cobden limestone, also present in the Ototara stone, warrants the reference of these beds to a period anterior to that of any Tertiary deposit in the Islands, the oldest

of which is at least Middle Eocene, and separated by an unconformity from the underlying beds. To distinguish this latter the term 'Cretaceous-Tertiary' has been made use of, as it is believed that the series bridges over the gap which separates the Lower Eocene from the Cretaceous rocks of Europe." (Hector, 1882, pp. xxii-xxiii.)

Park (1888A) in commenting on the stratigraphical and palaeontological difficulties in the correlation of two distinct groups of beds, "the one characterized by a fauna and flora with a distinctly Tertiary facies, the other by forms of an equally pronounced Secondary type," put forward another argument as accepted by the supporters of the correlation, although Hector himself does not seem to have used it in his writings: "The relation existing between these two groups has not been very satisfactorily determined, but they are at present supposed by the Survey to be in a manner horizontal equivalents—that is, the result of contemporaneous deposition, the Tertiary strata being taken to represent the shallow-water, and the Secondary strata the deep-water, conditions of the same period."

It appears probable also that the fossils of the Selwyn Rapids beds in the Malvern Hills greatly strengthened McKay and Hector in their belief in the correctness of the correlation of the "saurian beds" and Waipara greensands with the greensands underlying the Ototara limestone in South Canterbury and Otago. The Selwyn Rapids beds lie a little distance above an *Ostrea* bed extremely similar to that in the Waipara district, and the nature of the rocks is similar to that of the "saurian beds." No one has ever questioned that the Selwyn Rapids beds belong to a horizon below the Amuri limestone. The majority of the fossil Pelecypoda, however, belong to or closely resemble genera which are common in the Tertiary, and von Haast originally believed the fauna to be a Tertiary one. As these beds lie geographically between the North and South Canterbury localities, they seemed to offer themselves as a stepping-stone in correlation. The Cretaceous-Tertiary formation was supposed for some geographical reason to contain fewer distinctively Cretaceous forms as it was traced south.

The flaw in Hector's argument, by which it falls to the ground, is the incorrectness of his premise that the great mass of the molluscan fauna associated with the saurians in northern Canterbury agrees with that of the coal rocks in other parts of New Zealand. Woods's examination of the Pelecypod fauna associated with the saurians failed to bring to light a single species known from the rocks of the Oamaru and South Canterbury or the West Coast coalfields, and there is little reason to suppose that the case will be any better when the gasteropods are described.

Hutton (1885 B, c) perceived clearly the flaws in Hector's arguments, but his criticisms were weakened by two circumstances. The first was that the Upper Cretaceous faunas were not described, and the only satisfactory collections were those of the Geological Survey, which were inaccessible to him. The second was his own mistake in regard to the Pareora system. In this he included the Awamoan beds and all the Otago and South Canterbury localities now correlated in the Awamoan; but he also included in it the Waiareka greensands, the Enfield beds, and the Hampden beds, which are clearly below the Ototara limestone. He pointed out the distinctively Tertiary facies of the faunas of these beds, as opposed to the Cretaceous facies of the beds below the Amuri limestone; but in claiming that these beds lay above the Ototara limestone he gave McKay (1887B) a handle for upsetting a part of his criticism, although a part that was not really essential to the problem. Consequently Hutton's criticism of the correlations assumed by the Cretaceous-Tertiary theory failed to carry conviction to Hector and McKay, or to gain general acceptance.

Park's revision of the marine Tertiaries (1905) helped to emphasize the purely Tertiary nature of the supposed Cretaceo-Tertiary rocks of South Canterbury and Otago. The recognition by Uttley and Thomson (1914) of the infra-position of the Waihao greensands in respect to the Ototara limestone, together by the demonstration by Woods (1917) of the purely Cretaceous nature of the beds below the Amuri limestone in North Canterbury, removed the weaknesses of Hutton's position. His criticism thus reinforced is absolutely destructive of the correlations assumed by Hector.

The Cretaceo-Tertiary theory thus failed both in its classification of the rocks of the northern province (Rakaia River to Kaikoura Peninsula), and in its correlation of the rocks of the southern province (Kakanui River to Rakaia River). By falsely correlating Piripauan with Waiarekan rocks it failed to recognize the diversity between these two provinces. It failed also, owing to false correlation of the Piripauan and Clarentian rocks, to recognize the diversity between the northern of these two provinces and that extending from the Hapuku River to Cape Campbell. The Cretaceo-Tertiary theory of Hector must be absolutely discarded. Until we have new accounts of all Notocene localities, however, it will be necessary for the student to have a clear understanding of Hector's classification and its fallacies, because for many localities McKay's accounts of the stratigraphy are still the only or the best accounts available, and they are all couched in terms of this classification.

HUTTON'S CLASSIFICATION AND ITS SUCCESSORS.

Hutton's final classification (1900) of the younger rocks of New Zealand differed little from that he proposed in 1872, and was as follows:—

Cainozoic system—

Wanganui series	..	..	..	Newer Pliocene.
Glacier epoch	..	..	..	Older Pliocene.
Pareora series	..	..	..	Miocene.
Oamaru series	..	..	..	Oligocene.
Waipara system	..	..	..	Upper Cretaceous.

His views of the diastrophic history during these periods are contained in the following extracts: "About the middle of the Jurassic period folding of the rocks [of the Hokonui system] occurred along the same north-east and south-west axis; the Alps were formed, and the present land of New Zealand may be said to have been born, for since then it has never been submerged. . . . In the Upper Cretaceous the land subsided, and New Zealand was reduced to comparatively small limits. . . . A little before the commencement of the Tertiary era the rocks were folded once more, the land rose again. . . . This was the last folding of rocks in New Zealand on an extensive scale, for all the younger rocks usually lie in the same position in which they were originally deposited, and circle round the bases of the hills formed by older rocks. Not only was the last touch given in the Eocene period to the internal structure of the mountains, but the chief valleys were also deeply scoured out, so that when the land sank again in the Oligocene period these valleys were filled up with marine limestones and other rocks. The Oligocene and Miocene were periods of depression separated by a slight upheaval which lasted only for a short time. . . . In the older Pliocene came the last great upheaval. All the islands were joined together, and the land stretched away to the east and south. . . . On the mountains of the South Island large glaciers were formed, and the torrential rivers running from them tore into disconnected fragments the Miocene marine rocks which obstructed their valleys,